End-user Facilitated Interoperability in Internet of Things

Visually-enriched User-assisted Ontology Alignment

Oleksiy Khriyenko, Vagan Terziyan, and Olena Kaikova
IOG group, MIT Department and Agora Center
University of Jyväskylä, P.O. Box 35 (Agora)
FIN-40014 Jyväskylä, Finland
e-mail: oleksiy.khriyenko@jyu.fi, vagan.terziyan@jyu.fi, olena.o.kaikova@jyu.fi

Abstract — **Nowadays, we make a separation between the real/physical world and the Internet. It is time for these two be blended and provide ubiquitous access and interoperability online. We are approaching Internet of Things - a forthcoming technological revolution that will radically change our environment and enable innovative applications and services. To make this happen, we have to eliminate the fragmentation in used technologies and have to make the devices be used across various applications and services. We need to find a way to actually carry out the necessary and massive deployment of ubiquitous devices. So we need to put more effort into the design of tools to automate deployment and configuration of devices. This paper tackled a problem of an effective way to support interoperability in Internet of Things. We consider human as a very powerful asset in the world of ubiquitous systems and services that may provide his/her knowledge, experience and expertise. At the same time, we see a lack of human-oriented systems and infrastructures to support such a new role of a human. With a respect to the above statements, authors propose visually-enriched approach for user-powered ontology alignment to facilitate semantic interoperability in the Web of Things.**

Keywords- Mashup supported semantic visual mapping; visual ontology alignment, visual semantic human interface, semantic interoperability.

I. INTRODUCTION

This paper is an extension of the original paper [1] that has been presented at the international conference UBICOMM-2012. Here, authors extend the paper with more details regarding required semantic language extension for visually-enriched ontology and resource description, and present browser for visually-enriched linked data.

Our current Digital World is changing rapidly. We are about to enter a new era of ubiquitous computing and communication that will radically transform our corporate, community, and personal spheres. Tomorrow's world of Ubiquitous Pervasive Computing and Internet of Things is a technological revolution that represents the future of computing and communications and its development depends on technical innovations in a number of important fields. In the interconnected world of computers, interactions occur, not only between humans and applications, but also between applications of various kinds, applications and equipment, low-level software units, or any other logical or physical entities. Unlimited interoperability and collaboration are important values for a multitude of areas in our daily life.

With a purpose to better understand a need of proposed contribution, and highlight possible requirements and characteristics of interoperable systems, let us start with some short samples of use case scenarios:

Scenario 1: Person is traveling by a car. Suddenly, something is happened with the car and it needs to be repaired. Instead of searching the nearest car service station, booking a time and filling a request form describing current state of the car; the car itself searches for correspondent services in the web, collects necessary data from the correspondent modules of the car and books a time for maintenance service. During the maintenance, the car gets new spare-parts and integrates them to the central diagnostic system of the car (regardless of the fact that parts are produced by different vendors). In the same manner, car might negotiate and book appropriate time for annual technical check-up taking into account timetable of the owner, been connected to his/her personal organizer. During the trip, car might suggest optimized schedule of refueling taking into account fuel consumption, location of gasoline stations and their prices, discounts and bonuses available for the driver and other relevant contextual information.

Scenario 2: Person has bought "smart-home" system from some vendor. Vendor installs smart-home network with a set of smart-entities (sensors and actuators) and one control unit. So far, all the elements of the network belong to the same vendor and interoperate via the same ontology and communication protocol. A couple of month later, house owner buys a new smart-entity for good price from another vendor and connects it to the existing network. Later, friend of the house owner suggests some generic software application, which could be used as an upgrade of the smart-home network control unit and provides new useful features in comparison to the functionality of initial software of the control unit. This software application is produced by totally different vendor, and still can be installed to the control unit and communicate with all the connected to the smart-home network entities.

Scenario 3: Person has several measurement units (produced by different vendors) that can measure his/her heartbeat rate, arterial pressure, distance person walked or run, and some other parameters related to his/her health condition and physical activities. Person easily connects all these devices to a smart-phone to be able to log and observe them. Later, from an app. store, person buys application that suggests correspondent diet, taking into account all the measured personal data. Entering a supermarket and to be connected to the local infrastructure of it, application starts to navigate person to the correspondent location of the suitable products for his/her diet or alert the person when he/she puts to the basket a product which consists inappropriate ingredients.

All mentioned above stories are not fantasies. It is our tomorrow and, in some cases, even our today. Unfortunately, in case of our today, we have integration of systems produced by the same vendor. Supporting one interoperability model in several products, vendor creates integrated environment for various applications and interaction scenarios to be run on it. All these applications should support correspondent predefined API and data model. But, it is not what we expect to be in our tomorrow. We need an open environment with possibility to integrate various systems and components (hardware, apps, communication channels, etc.) produced by different vendors (see Figure 1). With a goal to achieve such requirements, we are approaching Internet of Things - a forthcoming technological revolution that will radically change our environment and enable innovative applications and services.

Above the personal level, the IoT will also have an important impact on enterprises and on society in general. IoT will enable a global connectivity between physical objects (connecting "things", not only places or people), will bring real-time machine-published information to the Web, as well as will enable a better interaction of people with the physical environment by combining ubiquitous access with ubiquitous intelligence. IoT will consist of a heterogeneous set of devices and communication strategies between them. Such a heterogeneous system should evolve into a more structured set of solutions, where "things" are uniformly discoverable, enabled to communicate with other entities, and are closely integrated with Internet infrastructure and services, regardless of the particular way (RFIDs, sensors, embedded devices) in which they are connected to the IoT. In this context, one of the challenging bottlenecks is to support interoperability between "entities" on a semantic level [2][3].

Taking into account current state of the art in the field of innovative research and development, we see lack of human-oriented systems and services. Now, human becomes very dynamic and proactive resource of a large integration environment with a huge amount of various heterogeneous data and services. As a user, human requires a technology and tools for easy and handy information access and manipulation. Moving from industrial era to the era of ubiquitous services, human is not considered only as a user/consumer any more. Human becomes a service provider, an expert that provides her/his knowledge and expertise to the digital world. Transition from an industrial welfare society to sustainable human-centric services society requires elaboration of correspondent infrastructure and tools to allow people add value to the process. Therefore, in this paper we propose an approach towards visually-enriched semantics as an infrastructure for user-powered semantic technology enhancement. The main contributions of the paper are visually enriched ontology and a system that visually assist users to execute semantic alignment.

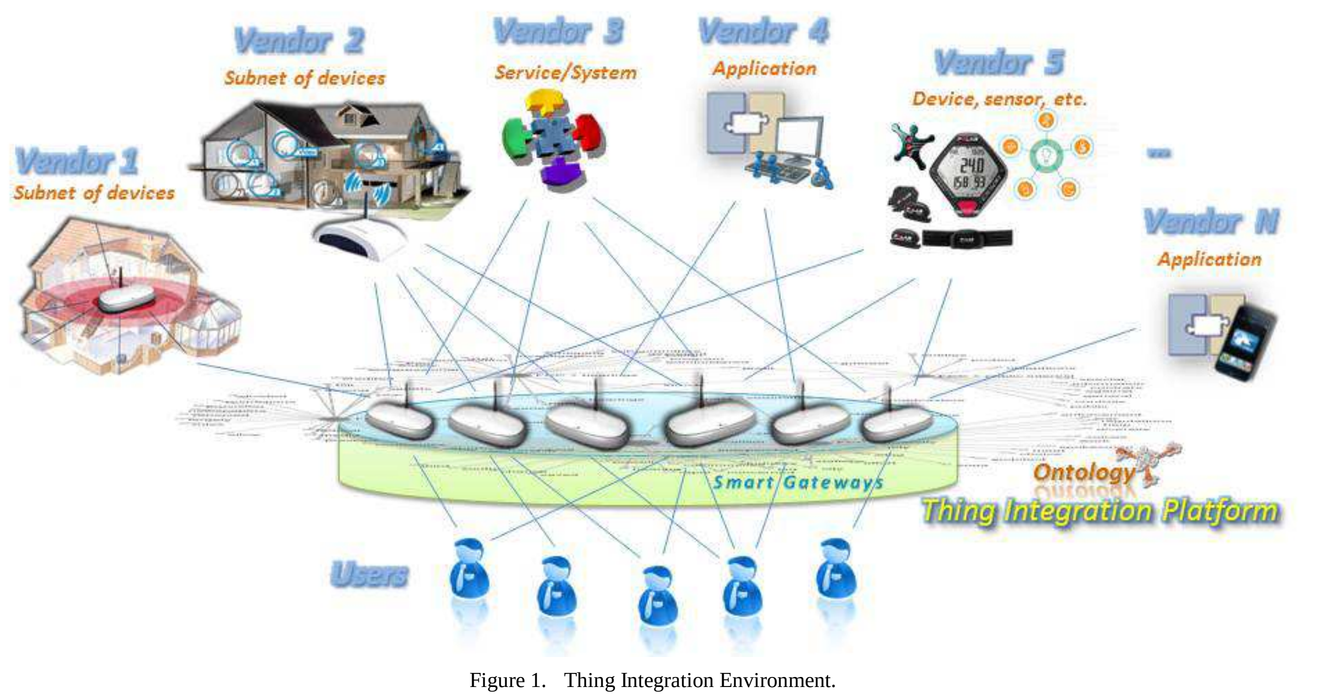

Figure 1. Thing Integration Environment.

Paper consists of two main sections: Section II and Section III. Section II addresses semantic integration platform for IoT and a vision of user-powered consumption of semantic technologies. Section III presents visually-enriched approach for user-powered ontology alignment to facilitate semantic interoperability in the Web of Things. Section IV presents author's conclusions with respect to the proposed contribution and defines future work.

II. THING INTEGRATION ENVIRONMENT

A. Smart Gateway - semantic integration platform for IoT

We are already in the middle of era of automated machine communication. There is already a lot of machine-to-machine communication going on out there; parking meters are connected, and vending machines automatically report when new supplies are needed. Every minute huge amount of data are being exchanged between machines for various purposes within various sectors. However, there is a big challenge in moving beyond application-specific devices and establishing an information model that will create re-use of the data generated by devices for new applications in different domains.

Finding the right horizontal points in the solutions is a key. There are already useful deployments within the transport, automotive, building, health and utility sectors, but everything is still very sector-specific. We need to create an infrastructure that will make information generated from a car or a building understandable not only within their own specific application/system, but across of various applications and domains. The vision of an open and interoperable IoT implicates ability:

- to have a growing environment with possibility to install and interconnect all IoT devises and software (services and applications) on the fly;
- to interconnect devises produced by different vendors;
- for third parties, to elaborate generic applications and services for IoT environments in the sense of applying them on various IoT device sets (same purpose, but different vendors).

To satisfy such requirements, IoT will require interoperability at multiple levels and rely on the benefits of the semantic technologies. On the hardware side, such problems have to be addressed as handling a capability mismatch between traditional Internet hosts and small devices, as well as handling widely differing communication and processing capabilities in different devices. In the interface between the device and network domains, IoT gateways will provide a common interface towards many heterogeneous devices and networks [4]. We assume that all "things" (devices, sensors, actuators, etc.) are connected to the web. Digital "things" such as services usually are accessible through the web. Applications might be downloaded and installed to the integration platform - Smart Gateway. Thus, we have correspondent requirements for such a platform. Smart Gateway should allow installation of applications and further configuration of communication model with it, based on accompanied annotation of the application. In case of services, Smart Gateway should be able to access semantic annotation through service access point and configure communication model with it as well.

Talking about physical world objects (device, sensors, etc.), usually they are accessible through the gateway - a control unit of a network provided by the same vendor. The only requirement - gateway should be presented in the web as a service with a set of capabilities provided by "things" connected to the gateway (providing data or doing some actions). In case we cannot have single "thing" personally connected to the web, we should deal with sub-network that consists of mentioned "thing" and correspondent gateway. Thus, we will have a set of gateways connected to the web and ready to become a part of the integration environment. Having all the gateways accessible as web-services, all connected to them real world "things" become digital entities and might be registered to the Smart Gateway.

Depending on a business model, Smart Gateway might be a part of a gateway, provided by certain vendor. In such a way, vendor can promote own network solution as an extendable open environment that support connectivity and interoperability of various entities produced by other vendors. Having Smart Gateway as a part of local network of connected "things", services and applications is a reasonable model in case of time-limited and highly secured runtime systems. At the same time, Smart Gateway might be considered as a separate integration solution - services located in the Cloud and accessible through the web. Been easily accessible, such "thing" integration service might be very popular among ordinary people who would like to create and manage their own distributed smart spaces, integrate various services with ubiquitous "things". Relevant research has been done in "Smart Resource" and "UBIWARE" Tekes projects with respect to Global Understanding Environment (GUN) [5].

B. User-powered consumption of semantic technologies

To achieve the vision of ubiquitous 'things', the next generation of integration systems will need different methods and techniques to provide connectivity, interoperability and intelligence of distributed entities, as well as smart and intuitive mechanism of communication with a human. Among those there are technologies such as Semantic Web [6][7], Web Services [8][9], Mashups [10], Linked Data [11][12], etc. To integrate 'things' seamlessly with the existing Web infrastructure and to represent interconnected 'things' uniformly as Web resources, resulting Web of Things (WoT) is a good facilitator of interoperability. Making devises able to unambiguously exchange the meaning of data, Semantic Web technology can be used to extend WoT into Semantic Web of Things (SWoT).

Semantic based technologies are viewed today as key technologies to resolve the problems of interoperability and integration within the heterogeneous world of ubiquitously interconnected objects and systems. Semantic Web is a vision with an idea of having data on the Web defined and linked in a way that it can be used by machines not just for display purposes, but for automation, integration and reuse of data across various applications. Semantic Web is considered as a standardized approach to achieve automated interoperability of heterogeneous systems/applications. Heterogeneity of systems and various data sources become a bottleneck for automated service integration, data processing and reuse. To make data ready to be consumed and processed by external systems, data sources and data should pass through the semantic adaptation [5][13] and be accessible in common uniform way. Due to the huge amount of application areas that Semantic Web technology tried to cover, community started to elaborate different standards and techniques to solve interoperability problems. As a result, we have a big variety of separated islands of information and management systems. These information islands internally follow the Semantic Web vision, but are heterogeneous from the general (global) interoperability point of view. This leads to the fact that society and especially its business-oriented part has started to doubt that such widely spread activity will be so much beneficial for them. Only some applications and systems in restricted domains became really useful. Most probably, the reason for this is the decentralization of uncontrolled activities, which creates new problems on the way towards ubiquitous Semantic Web. There are no doubts that Semantic Web is a very promising technology, but it definitely lacks more smart management or at least an environment that plays coordinative and supportive role and directs users towards proper technology utilization.

Services providers, as well as producers of “things”, are the end users of the service-oriented technologies. They need appropriate controlled support from the infrastructure that facilitates interoperability of services/devices, integration of heterogeneous data sources, and provides platform for new services/application development. Thus, we have to provide such a coordinative and supportive environment that will facilitate development and growth of service and smart-entity market. With respect to the current state of the art, we cannot expect that community of service providers and smart-entity vendors will build one global integration infrastructure with common ontology. We cannot expect that someone else (alone or in a consortium) will do the same. Current achievements in the area of interoperability of heterogeneous systems present technologies and tools for experts to build and manage adapters between heterogeneous systems or their components. Semantic Web is a technology for machines to better perform, providing services for human in automated or semi-automated way. In a case of unavailability of a common data model, we have to deal with semi-automated performance of the system when human become involved to the process not just as a consumer, but as an expert - necessary part in the chain to supervise and correct the process performed by machines [14].

With an increase in the development of ontologies, we need tools and techniques for solving heterogeneity problems between different ontologies. Therefore, we need ontology alignment [15][16][17][18], which helps us to bring different knowledge representations into mutual agreement. With respect to the scenarios mentioned above, ontology definitions of all the smart-entities and applications/services should be (semi-)automatically aligned by control unit of the network to ensure interoperability of them in a unified way. Regarding to the mentioned ontology alignment techniques, we may expect automatic alignment for simple and similar ontologies, but in all other cases, we will definitely need a human be involved into the process. This is largely a human-mediated process. There are existing tools that can help with identifying differences among ontologies [19], but user interaction is still essential in order to control, approve, and optimize the alignment results.

Unfortunately, approaching the era of ubiquitous services and IoT, we cannot expect availability of huge amount of professional experts involved to the daily processes of “things” interoperability support. We have to find a solution to bring technology closer to the ordinary user and make him/her able to not only utilize services, but to setup, configure and supervise interoperability process. We expect a human to be not only an end-user/consumer of technology world, but also to become an integral part of it, providing own expertise and capabilities. In all mentioned scenarios, person (owner of the smart-network) should be able to help the system to perform a proper ontology alignment through correspondent human interface of the alignment system. Owner of interoperable system does not only consume a service delivered by smart machines, but also plays a valuable role as a supervisor of interoperability process. Therefore, among variety of other adapters between heterogeneous entities, bridge to the human (human-to-machine H2M and machine-to-human M2H interfaces) becomes one of the most important tools of next generation integration infrastructures.

Such an adaptation of the human to the technology world might be provided by Personal Assistant (PA) - supportive agent assigned to every user [14]. From one side, it should deal with human personality and adapts to his/her personal ontology and personal perception of environment. From another side, it should support common semantic standards and approach to be interoperable with other surrounding digital world entities (applications, services and systems). The main features of PA (among others) are:

- Enabling personal user ontology creation and ontology driven resource annotation;
- Ability to adjust to the personal user ontology, to the way user perceives the environment, information and knowledge;
- Ability to build personalized semantic mind-map based on user behavior and preferences;
- Enabling personalized natural user-driven way of querying, filtering, browsing and presentation of information.

Personalized representation of information very much concerns a human supervised ontology alignment process. Ontologies very much differ from each other. The more specific, detailed and complex ontology we make, the more semantic value it has, but, it makes harder to integrate ontology with others. Taxonomies of different ontologies are not likely to be the same. Even developed by professionals, we still have different ontologies for the same problem domain. It would seem that experts, involved to the same domain, should operate with the same terms, use the same vocabulary and knowledge representation model. But, people are different, context and personal perception of surrounding world brings problems to interoperability process. As a part of the processes, human brings a certain level of uncertainty, and only human my help to solve the problem so far. Thus, to avoid heterogeneity in the resource annotations and simplify ontology alignment for automated interoperability between digital elements of the technology world, we may admit a necessity of personalized adaptation of every human (no matter whether it is an expert (knowledge provider) or user/customer) to the common information/data model.

In the next section we present an approach towards visually-facilitated human-assisted ontology alignment for automated interoperability among various heterogeneous entities of IoT. This approach supports the idea of end-user involvement as a powerful intelligent entity if IoT.

III. Human-assisted visual ontology alignment

A. *Visually-facilitated semantic matching*

Let us consider a scenario of installation of a new floor-heating regulator to a “smart-home” system. Assuming that we have two different vendors (Vendor A - producer of the Control Unit for the smart-home system, and Vendor B - producer of the regulator for a floor-heating system), we have two different ontologies $Ontology^{V}_{A}$ and $Ontology^{V}_{B}$. Vendor A logically defines all the floor-heating systems with respect to the room the system is associated with. Thus, $Ontology^{V}_{A}$ might contain such concepts as: living room floor-heating system, bedroom #1 floor-heating system, bedroom #2 floor-heating system, kitchen floor-heating system, bathroom floor-heating system, etc. From the Vendor A point of view, all these concepts refer to absolutely different sub-systems in the “smart-home” network. On the other side, association of the floor-heating system with particular room/place does not matter for Vendor B. Therefore, “floor-heating system” concept in the $Ontology^{V}_{B}$ is a more general and independent entity. Moreover, most probably “floor-heating system” concept will be named very much different in those two ontologies and automated alignment will be absolutely impossible.

Since the Control Unit of the smart-home is a more general device (in comparison to specific Floor-heating system) and deals with many other devices and systems in the installed network, it utilizes more wide ontology. Therefore, to allow interoperability between the Control Unit and Floor-heating system, we have to map $Ontology^{V}_{B}$ to wider $Ontology^{V}_{A}$. At the same time, we have to pay attention to the user’s (“smart-home” owner’s) $Ontology^{H}_{i}$. In general case, every human has own personal ontology that will be supported by his/her PA for interaction with devices, services, applications and systems. But, for any system/application, to be a mediator between the human and some other system with its own ontology, personal human ontology itself should be mapped with ontology of mediator-system in advance. PA will collect correspondent alignments of personal human ontology with ontologies of various mediating systems that human will be interacted with.

Assuming that fully automated alignment is not possible, we do not consider the cases with very simple and self-descriptive ontologies, where automated alignment might be done based on matching of synonyms of the property manes. Correspondent example of the research at this direction is a work performed in the Tivit SHOK IoT project (funded by Tekes, Finland), where authors are trying to minimize human involvement to the process of establishing interoperability between heterogeneous systems [4]. They try to retrieve (to build) ontologies from examples of massages that systems operate in communication process (requests, response, etc.). Authors build simple plane ontologies based on names of parameters used in the messages. Later, ontologies are automatically aligned and correspondent alignments are used for automatic interoperability between heterogeneous systems in runtime. But, as was mentioned, it might work in case of self-descriptive messages, where parameters are named by words that make sense, without abbreviations and shortenings, and preferably in the same language. In all other cases (cases with complex hierarchy of sub-classes, cases of different domain description models, cases of multilingual and multicultural ontology definitions, etc.), this would not work automatically and will require human assistance. Thus, in cases of human-assisted alignment of personal human ontology or ontologies provided by different vendors, we need an innovative suitable for non-expert mechanism and correspondent user interface for ontology alignment.

With respect to the research [20][21][22][23], there are some available Ontology Alignment and visualization tools: Foam algorithm [24], multiple-view plug-in for Protégé [25] - AlViz [26], BLOOMB system [22] and Knowledge Modeler[27]. The very good overview of visually supported ontology alignment tools is presented in the paper [28]. There graphical primitives such as point, line, area, or volume are currently utilized to encode information. These objects are characterized by position in space, size, connections & enclosures, shape, orientation, and visual cues like color and texture, with temporal changes, and viewpoint transformations. Unfortunately, all these tools were elaborated for domain experts who know what ontology is and what information models might be used. Such tools present a lot of statistical data and analytics that might be very useful for the ontology engineer, but not for the ordinary user of a service. Information visualization should aim at making complex data easy accessible and understood for interactive investigation by the user. In case of smart-home, we expect that user has a basic knowledge about a domain and functionality of the system. Like in the scenario above, house owner knows already available sub-system of his/her smart-home, their purposes and functionality, as well as he/she knows a purpose of the new parts that he/she wants to be added to the system. Therefore, we have to find more suitable approach for user-assisted ontology alignment.

To be easily recognized by human, concepts and properties of different ontologies must be presented in the most understood form - in a form of image. An image (or other visual form) is the most common information representation model for human. It helps to understand the meaning and avoid verbal uncertainty presented in textual form. Therefore, user interface should be able to present semantics through interactive image mash-ups and userfriendly browsing mechanism. Talking about data visualization, we would like to admit existence of some domain-oriented software applications, which try to visualize data in domain specific and suitable for human way (graphics software from SmartDraw®, concept-browser Conzilla and Human Semantic Web browser Conzilla2, etc.). But still, they are developed for specific standalone domain-oriented applications. And when we face a real need in an open unlimited collaboration environment, we have to develop much more visualization tools and modules that are aimed to visualize various resource properties, contexts, situations and associations to provide human flexible and handy Human-Machine interaction interface. Thus, semantic-based context-dependent multidimensional resource visualization approach and 4i (FOR EYE) technology [29][30][31] can be a basis for the development of such interface. The idea of intelligent resource visualization is to simplify the search and browsing processes via associative resource visualization. Multidimensional associative resource visualization means visualization of a resource depending on a context, via association with various aspects of resource being (relations with the other resources, domains, areas of interest, etc.). Sometimes, we cannot specify exactly what we are looking for, but we feel that it is somehow related to certain stuff, certain situation, certain context. Such visualization can give us a hint, turn to the right direction, show us related objects and provide links to them. In other words, visualization will utilize context-based filtering and enrichment of the visualized scene with the relevant links. Such approach provides an opportunity to create intelligent visual interface that presents relevant information in more suitable and personalized for user form. Context-awareness and intelligence of such interface brings a new feature that gives a possibility for user to get not just raw data, but required information based on a specified context. Now it has become evident that we cannot separate visual aspects of both data representation and graphical interface from interaction mechanisms that help user to browse and query a data set through its visual representation.

Figure 2 shows us possible visual interpretations of the Vendor A, Vendor B, and user (smart-home owner) ontologies with respect to the scenario of adding the living room floor heating system to the "smart-home" network. Since we are not consider "smart-home" owner as an expert in ontologies and complex control systems, we cannot expect that it would be possible for him/her to utilize currently available solutions for ontology alignment. Only we can expect is awareness of the user about purpose, capabilities and main functionality of the "smart-home" Control Unit and floor-heating system that he/she would like to add to the "smart-home" network. Having even such limited expertise of the problem domain, user is able to browse visual description of the Control Unit (the structure of sub-systems,

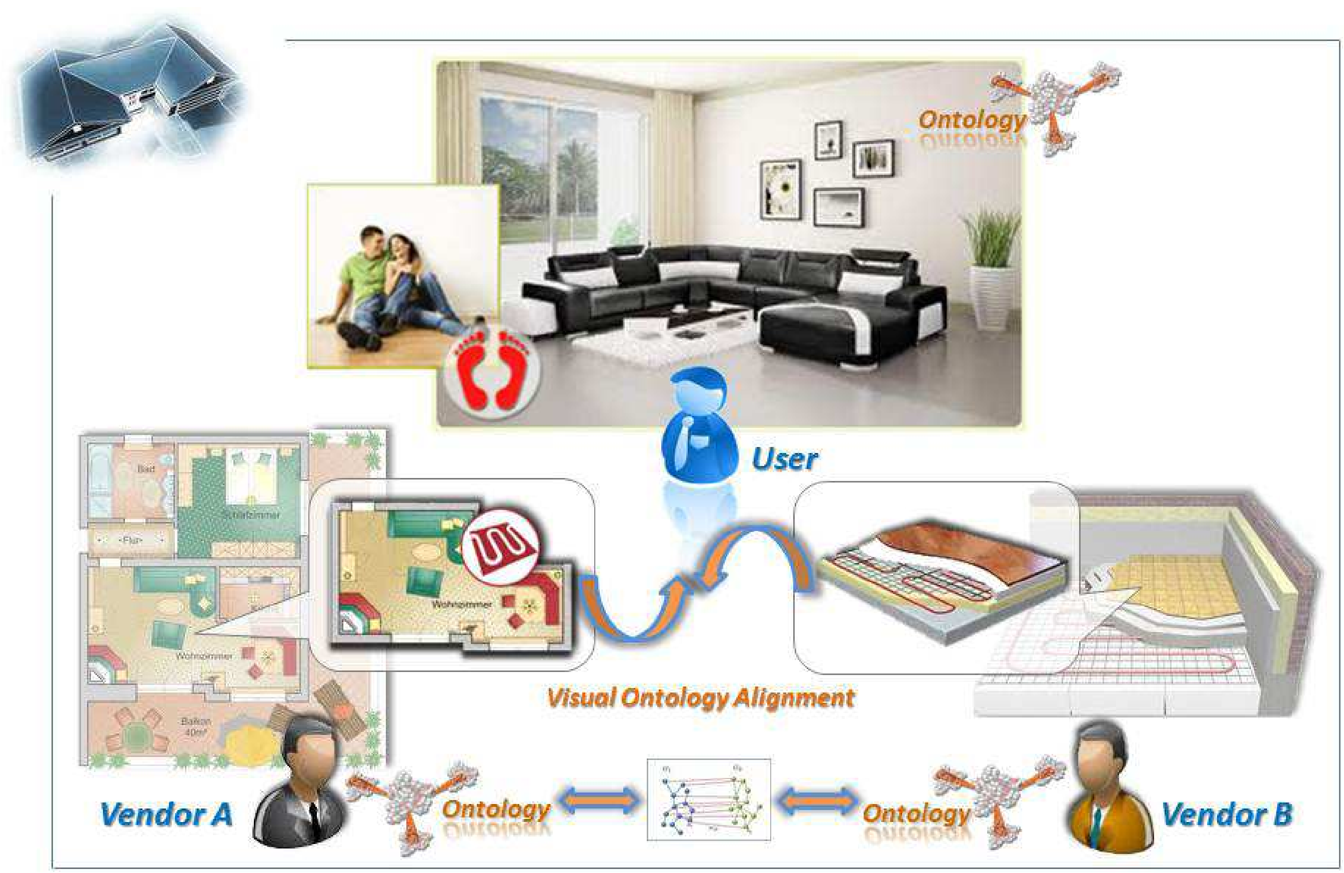

Figure 2. Visually-facilitated Ontology Alignment.

capabilities, inputs and outputs, properties, etc.) and description of the floor-heating system from another vendor to provide appropriate matching. User can intuitively map concepts and properties presented by images. Applying possible results, achieved by integrated modules of automated ontology alignment (as a background process), Visual Ontology Alignment Tool assists user with suggestions and requests next necessary alignments caused by alignments made on the previous steps. Additional textual descriptions of visual annotations support user to make correct mapping. As a result, correspondent parts of ontologies OntologyVA and OntologyVB, which are related to the communication scenario between “smart-home” Control Unit (Vendor A) and floor-heating system (Vendor B), will be mapped and correspondent alignment will be used in runtime operation of the “smart-home” network.

B. Visually-enriched ontology and resource description

To operate with visual representation model in a smart way, visualization tool should retrieve correspondent images together with ontologies. It means that ontologies should be extended with additional layer that contains visual definition of the concepts (classes and properties). Later in the text, we will call such visually-enriched ontology as Visual Ontology (VisOntology). We consider two scenarios of human-assisted visual enrichment of data (see Figure 3). In the first case, Ontology/Domain Expert creates VisOntology using Ontology Visual Enrichment Tool that adds correspondent image layer to the ontology. Later, Vendor provides annotation of the Service/System that was produced by Vendor. In the second case, Vendor itself provides visually-enriched annotation (VisAnnotation) of the produced Service/System using Visually-enriched Resource Description Tool based on regular domain ontology provided by Ontology/Domain Expert. In this case, visually-enriched ontology might be automatically created from the visually-enriched resource description during the annotation process. In case when it is difficult to associate any image with some of the concepts, tool will create an image with a correspondent text (word, character, sign, etc.) retrieved from the name of ontology element. One more scenario might have a place if we consider possibility for some third party to substitute Vendor in the Service/System annotation process and provide visual annotation in both previous cases. Both tools that were mentioned in the above scenarios have the same nature and similar functionality. Thus, let us consider them as a single tool for visual semantic enrichment.

The best way to provide visual layer to the ontology is to extend existing ontology editors (the most popular - Protégé ontology creation and editing tool) with possibility to assign appropriate visual element to every entity of ontology (class and property). Talking about instance annotation process, visually-enriched description might be performed via various RDF creation tools. It might be Protégé as well as any other more customized RDF creation tool which is more suitable for specific application domain. The main purpose of the tool is to help user to brows ontology and assign “visSemantics” property to every entity of ontology: class, property and instance. Taking into account formal aspects of a visual layer in ontology definition and resource description, we have to extend the RDF Schema (RDFS) [32] and Web Ontology Language (OWL) [33]. Figure 4 presents possible extension of RDFS or OWL with “visSemantics” property used for VisOntology and VisDescription. Talking about resource annotation, tool creates an annotation template based on assigned ontology and provides possibility to add visual description. In such a way, tool extends the concepts of the ontology with “visSemantics” property and correspondent value in a form of image. Currently we consider the range of this property as a literal URL of an image. In more advance version of VisOntology and VisDescription of the resource, the range might be extended to video, audio or any other multimedia content. Such extended range of the property might be regulated by rich datatypes that will restrict the type (file extension) of the file mentioned as a Literal value of the visSemantics property.

Visual enrichment is individual, as long as a set of images, used by VisOntology and VisAnnotation providers, is individual. Tools should allow user to make key-word based image annotation/tagging for individual content and create a personal pool of annotated visual content for further reuse. Later, annotated content (used for visual enrichment)

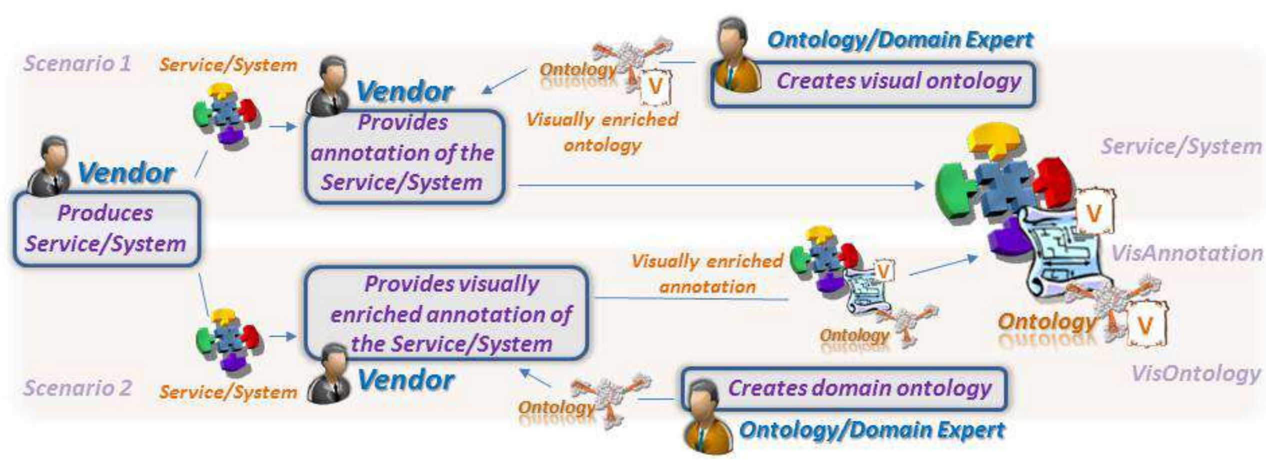

Figure 3. Human-assisted visual enrichment scenarious.

will be easily retrieved based on user search request or automatically suggested to a user based on attributes of self-descriptive elements of ontology. In case of old-fashioned service/system description which is based on ordinary ontology, enrichment of the description might be still automated on some extend. Based on the names of ontology concepts, Visual Enrichment Tool may search among visual content (annotated already), and build visual layer automatically. Quality of automated enrichment might be relatively low in comparison to human assisted enrichment. But, even in worst cases, when we do not have any human involvement at the stage of resource annotation, it might help to retrieve at least some visual content for further visual ontology alignment process. Taking into account growing trend towards sharing and reuse of content, annotated visual content might be shared through various clouds and common spaces. Thus, tool can use not only personal visual content of the user, but also will allow to manage and extend his/her virtual visual content space with external sources. In this case, Social Web might be considered as a good platform to share visual annotation content and VisOntologies.

Assuming that it might be not so popular for vendors to provide visual description manually, visually-enriched ontologies might become popular. Already having visual layer imbedded into ontology, resource annotation tool will suggest correspondent visual entity with respect to the class of annotated instance. Responsible for resource annotation expert might just simply accept such proposed visualization or provide customized visualization more suitable in particular context. Every time when expert select customized visualization, correspondent visual entity might be shared and will extend ontology with extra visual definition of correspondent class (or property). Multiple visual annotations of the classes and properties will enhance semi-automated resource definition process. Several appropriate visualization options will be proposed to annotation expert. To avoid redundancy of alternatives, they might be filtered based on automatically detected or specified (by annotation expert) context. This will require context definition for each visualization entity in the ontology (see Figure 4). In this example, we may see the definition of the contexts for two different images assigned to the HeatingSystem class (class of various heating systems). Context definition might be perform via reification mechanism and be defined either by context definition keyword(s) (via “visContextKeyWords” property) or by instance of the context definition class (via “visContext” property). Thus, the domain for both mentioned properties in rdf:Statement. In the example, we may find two different methods for applying reification mechanism. One of them uses abbreviation “{}” supported by Notation-3 [34] serialization to define a statement. Another method uses standard approach of RDFS via definition of an instance of rdf:Statement class. The range of the “visContextKeyWords” and “visContext” properties is different. Range for the first property is restricted by rdfs:Literal class and considered to be referred to keyword (key-sentence). At the same time, range of another property refers to the class of context definitions. In this paper we do not concentrate our attention on the context definition class.

```
@prefix :    <http://www.example.org/sample.owl#>.
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs:<http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.

rdfs:visSemantics
     rdf:type rdf:Property;
     rdfs:domain rdfs:Resource;
     rdfs:range rdfs:Literal.

owl:visSemantics
     rdf:type owl:DatatypeProperty;
     rdfs:domain rdfs:Resource;
     rdfs:range rdfs:Literal.

owl:visContextKeyWords
     a owl:DatatypeProperty;
     rdfs:domain rdf:Statement;
     rdfs:range rdfs:Literal.

owl:visContext
     a owl:ObjectProperty;
     rdfs:domain rdf:Statement;
     rdfs:range owl:ContextDefinition.

:HeatingSystem a rdf:Class .

owl:ContextDefinition a rdf:Class .

#---some definition of the context ---
:carHContext a owl:ContextDefinition .

#------------------------------------

{:HeatingSystem rdfs:visSemantics
“www.example.org/FloorHSystem.jpeg”}
     owl:visContextKeyWords
     “floor heating” ,
     “home heating” ,
     “room heating” .

{:HeatingSystem rdfs:visSemantics
“www.example.org/CarHSystem.jpeg”}
     owl:visContext :carHContext .

:statement_1 a rdf:Statement ;
     rdf:subject :HeatingSystem ;
     rdf:predicate rdfs:visSemantics ;
     rdf:object
   “www.example.org/CarHSystem.jpeg” .

:statement_1 owl:visContextKeyWords
     “car heating” ,
     “vehicle heating” .
```

Figure 4. “visSemantics” ontology extension and visualization context definition.

There are several approaches towards context definition, but in this paper we are just assuming an existence of some context definition class (in our example - “ContextDefinition” class).

Sub-class and sub-property hierarchy of the ontology also can help to collect visualization alternatives and automate resource annotation process. All the visualization entities that describe sub-classes and sub-properties also describe supper-classes and supper-properties. Even if certain class does not have any visual description/representation, the list of alternatives to describe an instance of that class will be retrieved from the sub-classes and the same context-based filtering technique might be applied to find more appropriate visualization. Thus, more detailed ontology with deep sub-class hierarchy might minimize amount of multiple context-dependent visualization settings. If we reconsider example in Figure 4 and define floor heating system and car heating system as sub-classes of more general class that defines all heating systems, then “HeatingSystem” class might be described by some general visualization and additional alternatives might be collected form visual descriptions of its’ sub-classes.

C. Browsing of visually-enriched linked data

Browsing of visually-enriched ontologies and visualization of visually-enriched resource descriptions might be performed by appropriate visualization tools. As was mentioned before, it is reasonable to have visualization of ontologies imbedded into ontology editors. At the same time, visually-enriched resource descriptions must be visualized in more intuitive way via smart integration of data mashups [29][30]. In this project, we have been used 4i (FOR EYE) Browser [31] - smart visual context-sensitive resource browser (elaborated in UBIWARE Tekes project) and Linked Data Browser (elaborated in this project for visualization of visually-enriched resource descriptions) (see Figure 5). 4i (FOR EYE) is an ensemble of Intelligent GUI Shell (smart middleware for context dependent combination of different MetaProviders) and MetaProviders, visualization modules that provide integration and context-dependent filtered representation of resource data. Context-awareness and intelligence of such interface brings a new feature that gives a possibility for user to get not just raw data, but required integrated information based on a specified context.

Figure 5. Browsing of visually-enriched linked data.

The Figure 5 shows us example of Linked Data browsing with respect to the heating systems imbedded into smart-home described in one of the scenarios in the beginning of the paper. Based on the resource description file that contains visually-enriched resource descriptions, one of the visualization modules of the 4i Browser has been used to present us all the heating systems available in the house. Another visualization tool (Linked Data Browser) has been used to browse the RDF graph from the same resource description source and show us certain smart-home with correspondent smart-home heating system that consist of four sub-heating systems for living room, bedroom, balcony, and bathroom.

IV. Conclusion and Future Work

Approaching the era of people-oriented systems, human becomes very dynamic and proactive resource of a large integration environment with a huge amount of different heterogeneous data. People are great asset to be utilized in servicing and services creation. Involving people to the process, we allow them be not only a user, but also add value to technology evolution.

With the aim to elaborate an environment that enables integration of heterogeneous “things” and intelligent distributed systems within the Internet of Things framework, authors address the mechanism of human-assisted simplification of semantic matching to allow interoperability of entities in the IoT. Assuming unavailability of a sufficient amount of professional experts to be involved to the daily “things” integration support process, authors proposed the way to make user be not just a consumer of thing-based services, but also an expert capable to compose and establish interoperability among the things. Taking into account specifics of the potential user and unsuitability of current ontology alignment tools for it, this paper presents a human-driven approach towards visually-facilitated ontology alignment through visually-enriched ontologies and resource (thing) descriptions. Authors have presented extension of RDFS and OWL ontologies to enable creation of visually-enriched ontologies and resource descriptions. Current implementation of correspondent toolset is concentrated on and consists of an interface for the final stage - Visual Ontology Alignment Tool that assumes existence of VisOntologies and VisDescriptions of Things. Implementation of the tool for visual enrichment of ontologies and resource descriptions is considered as a future continuation of presented work.

Acknowledgment

This research has been performed as part of IoT Tivit SHOK Program in the department of Mathematics and Information Technology (MIT, University of Jyvaskyla, Finland) funded by TEKES and consortium of industrial partners. Authors are grateful to the project team members from Industrial Ontologies Group (IOG) and colleagues from VTT research team (as well as other industrial partners of the project) who have been involved into the correspondent task and did provide fruitful cooperation.

References

[1] O. Khriyenko, V. Terziyan, and O. Kaikova, “User-assisted Semantic Interoperability in Internet of Things: Visually-facilitated Ontology Alignment through Visually-enriched Ontology and Thing Descriptions”, In: Proceedings of the Sixth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM 2012), Barcelona, Spain, 23-38 September, 2012, pp. 104-110.

[2] D.J. Cook and S.K. Das, “How smart are our environments? An updated look at the state of the art”. Pervasive and Mobile Computing. 3(2) , 2007, pp. 53-73.

[3] J. Honkola, H. Laine, R. Brown, and O. Tyrkko, “Smart-M3 information sharing platform”. Proc. IEEE Symp. Computers and Communications (ISCC’10), 2010, pp. 1041-1046.

[4] K. Kotis and A. Katasonov, "Semantic Interoperability on the Web of Things: The Smart Gateway Framework", CISIS 2012, Palermo, Italy, 2012.

[5] O. Kaykova, O. Khriyenko, D. Kovtun, A. Naumenko, V. Terziyan, and A. Zharko, “Challenges of General Adaptation Framework for Industrial Semantic Web”, In: Amit Sheth and Miltiadis Lytras (eds.), Semantic Web-Based Information Systems: State-of-the-Art Applications, CyberTech Publishing, 2007, pp. 61-97.

[6] Semantic Web, 2001. URL: http://www.w3.org/2001/sw/

[7] T. Berners-Lee, J. Hendler, and O. Lassila, “The Semantic Web”, Scientific American 284(5), 2001, pp. 34-43.

[8] A. Ankolekar, M. Burstein, J.R. Hobbs, O. Lassila, D.L. Martin, D. McDermott, S.A. McIlraith, S. Narayanan, M. Paolucci, T.R. Payne, and K. Sycara, “DAML-S: Web Service Description for the Semantic Web”, 2002. URL: http://www-2.cs.cmu.edu/~terryp/Pubs/ISWC2002-DAMLS.pdf

[9] M. Paolucci, T. Kawamura, T.R. Payne, and K. Sycara, “Importing the Semantic Web in UDDI”, 2002. URL:http://www-2.cs.cmu.edu/~softagents/papers/Essw.pdf

[10] EM. Maximilien, A. Ranabahu, and K. Gomadam, “An Online Platform for Web APIs and Service Mashups”. In IEEE INTERNET COMPUTING, IEEE Computer Society, 2008, pp. 32-43.

[11] T. Berners-Lee, “Linked Data - Design Issues”. 2006. URL: http://www.w3.org/DesignIssues/LinkedData.html

[12] T. Heath and C. Bizer, “Linked Data: Evolving the Web into a Global Data Space” (1st edition). Synthesis Lectures on the Semantic Web: Theory and Technology, 1:1, 1-136. Morgan & Claypool. 2011.

[13] O. Khriyenko and M. Nagy, “ Semantic Web-driven Agent-based Ecosystem for Linked Data and Services”, In: Proceedings of the Third International Conferences on Advanced Service Computing, Rome, Italy, 25-30 September, 2011, 8 p.

[14] O. Khriyenko, “Collaborative Service Ecosystem - Step Towards the World of Ubiquitous Services”. In: Proceedings of the IADIS International Conference Collaborative Technologies 2012, Lisbon, Portugal, 19-21 July, 2012.

[15] V. Spiliopoulos and G. A. Vouros, “Synthesizing Ontology Alignment Methods Using the Max-Sum Algorithm”, Knowledge and Data Engineering, IEEE Transactions on, vol.PP, no.99, pp.1-11.

[16] K. Kotis, A. Katasonov, and J. Leino, “Aligning Smart and Control Entities in the IoT”, In: Proceedings of the 5th Conference on Internet of Things and Smart Spaces, St.-Petersburg, Russia, 27-28 August, 2012.

[17] K. Kotis, A. Valarakos, and G. Vouros, "AUTOMS: Automating Ontology Mapping through Synthesis of Methods.", In: Proceedings of the International Semantic Web

Conference (ISWC'06), Ontology Matching International Workshop, Atlanta USA, 00/2006.

[18] A. Valarakos, V. Spiliopoulos, K. Kotis, and G. Vouros, "AUTOMS-F: A Java Framework for Synthesizing Ontology Mapping Methods", i-Know,07, Graz, Austria, 00/2007.

[19] P. Shvaiko and J. Euzenat, “Ontology matching: state of the art and future challenges”. IEEE Transactions on Knowledge and Data Engineering, 2012.

[20] J. Pina, E. Cerezo, and F. Seron, “Semantic visualization of 3D urban environments”. Multimedia Tools and Applications, Volume 59, Number 2 (2012), pp. 505-521, DOI: 10.1007/s11042-011-0776-3.

[21] M. Lanzenberger and J. Sampson, “Human-Mediated Visual Ontology Alignment”. HCI (9) 2007, pp. 394-403.

[22] P. Jain, P. Hitzler, A.P. Sheth, K. Verma, and P.Z. Yeh, “Ontology Alignment for Linked Open Data”. In: Proceedings of the 9th International SemanticWeb Conference, ISWC 2010, Springer-Verlag (2010), Shanghai, China, November 7-11, 2010, pp. 402–417.

[23] F. Kboubi, A.H. Chaibi, and M.B. Ahmed, 'Semantic Visualization and Navigation in Textual Corpus'. In: CoRR abs/1202.1841, 2012 .

[24] M. Ehrig and Y. Sure, “Ontology mapping - an integrated approach. In: Bussler, C., Davis, J., Fensel, D., Studer, R. (eds.) Proceedings of the First European Semantic Web Symposium, Heraklion, Greece, 10-12 May, 2004.

[25] Protégé-owl (Stanford Medical Informatics) - http://protege.stanford.edu/overview/protege-owl.html

[26] M. Lanzenberger and J. Sampson, “Alviz - a tool for visual ontology alignment”. In: Society, I.C.S. (ed.) Proceedings of the IV06, 10th International Conference on Information Visualization, London, UK, July, 2006.

[27] A. Sheth and D. Avant, "Semantic Visualization: Interfaces for exploring and exploiting ontology, knowledgebase, heterogeneous content and complex relationships," NASA Virtual Iron Bird Workshop, CA, March 31 and April 2, 2004.

[28] M. Granitzer, V. Sabol, K. W. Onn, D. Lukose, and K. Tochtermann, "Ontology Alignment - A Survey with Focus on Visually Supported Semi-Automatic Techniques," Future Internet, 2, 2010, pp. 238-258.

[29] O. Khriyenko, "Context-sensitive Multidimensional Resource Visualization", In: Proceedings of the 7th IASTED International Conference on Visualization, Imaging, and Image Processing (VIIP 2007), Palma de Mallorca, Spain, 29-31 August 2007.

[30] O. Khriyenko, "4I (FOR EYE) Technology: Intelligent Interface for Integrated Information", In: Proceedings of the 9th International Conference on Enterprise Information Systems (ICEIS-2007), Funchal, Madeira – Portugal, 12-16 June 2007.

[31] O. Khriyenko, "Context-sensitive Visual Resource Browser", In: Proceedings of the IADIS International Conference on Computer Graphics and Visualization (CGV-2008), Amsterdam, The Netherlands, 24-26 July 2008.

[32] RDF Vocabulary Description Language 1.0: RDF Schema. W3C Recommendation 10 February 2004. URL: http://www.w3.org/TR/rdf-schema/

[33] OWL Web Ontology Language. W3C Recommendation 10 February 2004. URL: http://www.w3.org/standards/techs/owl#w3c_all

[34] Notation3 (N3): A readable RDF syntax. W3C Team Submission 28 March 2011. URL: http://www.w3.org/TeamSubmission/n3/