Towards Cognitive Assisted Living 3.0

Integration of non-smart resources into an active assisted living solution

Claudia Steinberger, Judith Michael
Alpen-Adria-Universität Klagenfurt
Klagenfurt, Austria
{claudia.steinberger, judith.michael}@aau.at

Abstract – **Considerable effort to manually set up the user's context and too coarse-grained activity recognition results often handicap the assignment of active assisted living systems. In this paper we join our cognitive assistance system HBMS-System with the semantic web to (1) simplify the construction of inhabitant's behavior and context models and to (2) improve the system's activity recognition capability. We present how to describe resources like devices and appliances semantically to make them understandable for our HBMS-System and interoperable with its environmental context model. Clearly, benefits of this semantic markup approach beyond the HBMS-System are discussed. Moreover, we show how personalized and adaptive HBMS user clients and the power of the HBMS environmental context model can be used to bridge an existing activity recognition gap.**

Keywords – Semantic Manual; Cognitive Assistance: Schema.org; User Context Model; Simulated Sensor Data;

I. Motivation and Introduction

Smart home applications that monitor user behavior and support users completing their activities based on obtained behavior patterns can be very useful helping people who suffer from any kind of cognitive decline. In literature different approaches with the following main objectives can be found: (1) detection of activities, (2) task reminders to inhabitants, (3) detection of changes in routines as signs of possible risks or (4) diagnosis of specific diseases based on activity patterns. [1] give some significant examples of each of these approaches.

With the cognitive assistance system HBMS (Human Behavior Monitoring and Support)[1] we aim to actively assist people e.g. in activities of daily living, using user's episodic knowledge as well as information about user's environmental resources, social and personal situation and location [2]. The HBMS-System operates as an intelligent agent [3] and is able to support a user for example in 'preparing the breakfast', 'making the laundry' or 'leaving the house for shopping' by monitoring the user's behavior and interacting with the user sensitively and in multimodal form.

The needed user context knowledge is built up in HBMS in form of models, each of which is formed tool-assisted with the means of the domain specific modelling language HCM-L (Human Conceptual Modeling Language) [4]. The so constructed Human Cognitive Model (HCM) contains knowledge concerning different user context areas: behavior, environment, social and personal situation and spatiality [5] and builds the core of HBMS-System. It preserves knowledge in human as well as in computer readable representation form. By this way the HBMS-System has been realized as a model centered architecture [6] where user's goals, desires and intentions (according to the BDI-Model [7]) are built up in form of conceptual models. Reasoning over the HCM allows the HBMS-System to predict user actions and to guide him. Evaluating the HBMS-System we were faced with the following two problems:

(1) Setting up the HBMS-System, the *user's context had to be modeled manually*. Particularly, considerable effort was needed to model the user's environmental resources like devices and appliances together with their multimodal operating hints to build up the user's environmental context model. We had to rewrite large parts of the resource user manuals to enable the HBMS-System to assist the user and to guide him. *Replacing the resources* this work had to be *redone*.

(2) Activity recognition results concerning *fine granular user interactions* with devices and appliances where *not sufficient* for the intended user support. For context awareness the HBMS-System uses interfaces to context management middleware and activity recognition systems [6]. These systems use a combination of environmental and wearable sensors to gather contextual information about human activities. For *some activities*, which can be recognized with today's sensing infrastructure, this approach worked quite well during our system evaluation. But a large number of *fine granular actions* were not recognizable.

This paper presents an approach to overcome these challenges and to join the HBMS-System with the semantic web to simplify the construction of inhabitant's behavior and context models and to improve its activity recognition capability.

The paper is structured as follows: Section 2 presents the HBMS-System and HCM as well as our evaluation experiences in more detail. Section 3 deals with related work and the overall conditions for our research. Section 4 sketches our ideas to semantically enrich manuals and deals with related advantages. Section 5 shows how to use semantic manuals to import resource domain knowledge into the HBMS-System and also to recognize fine granular activities via personalized and adaptive user feedback. Section 6 summarizes our findings and gives an outlook to identified further research challenges.

[1] funded by Klaus Tschira Stiftung gGmbH, Heidelberg

II. HMBS-SYSTEM AND EVALUATION ISSUES

The HBMS-System aims at deriving support services using *integrated conceptual models of* abilities, the environmental and spatial context and the episodic memory of the supported user building up the Human Cognitive Model (HCM).

HCM has to be defined and customized for the individual user during each HBMS-System setup process whereby the tool *HCM-L Modeler* [8] enables to create and modify HCM models using the domain specific modeling language *HCM-L* [2]. Compared to knowledge based approaches for activity recognition [9] HCM models show the following advantages: (1) as conceptual models they allow a better readability for human readers (users, knowledge administrators) for customization and evaluation purposes [4] and (2) reasoning over the HCM allows the HBMS-System to predict user actions and to guide him. For this purpose HCM models are transformed into corresponding knowledge representation formats (like OWL).

Fig. 1 shows the meta-model of the HCM-L consisting of four interlinked clusters to describe a user's context: (1) The *Environmental Context* covers the **Resources** that are utilized in operations of the assisted user or are placed as equipment in his spatial context and participate in operations. **Applications**, **Items**, **Devices** and **Fixtures** specialize available resource types. (2) The *Personal and Social Context* of a supported user covers the user's profile and **Abilities** together with the level of ability fulfilment as well as the social setting. (3) The *Spatial Context* covers the **Location** in which the user should be actively assisted. (4) The *Behavioral Context* covers episodic memory patterns (as '**Behavioral Units (BUs)**') of the assisted user, which '**Goals**' are pursued and what actions ('**Operations'** connected by '**Flows**') a person should execute under which conditions to reach a goal [10].

For user monitoring at runtime the HBMS-System uses interfaces to existing context management systems and activity recognition systems like Nimbits [11]. The model based architecture of the HBMS-System is described in [6].

During the last year we evaluated the HBMS-System prototype in a smart lab with the aim to support a user in 'preparing the breakfast', 'leaving the house for shopping', 'using the home multimedia equipment' and 'using a webpage'. We modeled the corresponding HCM with the HCM-L Modeler, monitored the user's behavior and supported the user sensitively and in multimodal way guiding on demand through the modeled behavioral units (BUs) and their operations in more than 100 runs. Because of lack of user acceptance we did not use video or audio monitoring but only environmental and wearable sensor technologies for activity recognition.

In this evaluation we recognized two weaknesses:

1) *High degree of manual effort*: Setting up the HBMS-System we had to spend considerable effort to model the environmental context with used devices and applications together with their functionalities and multimodal instructions. Moreover, we had to adapt and detail large parts of the user manuals e.g. of the user's TV device, the coffee machine and remote controls to enable the HBMS-System to assist the user and to guide him. The term *manual* is used in the following as a synonym for user guide, user manual, operating instruction and user instruction. On replacing resources (e.g. a new coffee machine) the models had to be updated again.

2) *Detection of fine granular user's interactions*: For some user activities (e.g. open a door, press a button on a remote control, sit on a chair, switch on the light), which can be easily recognized with today's sensing infrastructure, user monitoring worked quite well. Nevertheless, activity recognition results concerning fine granular user's interactions with devices and appliances (like refill water or put descaler into the coffee machine) where not sufficient for the intended user support.

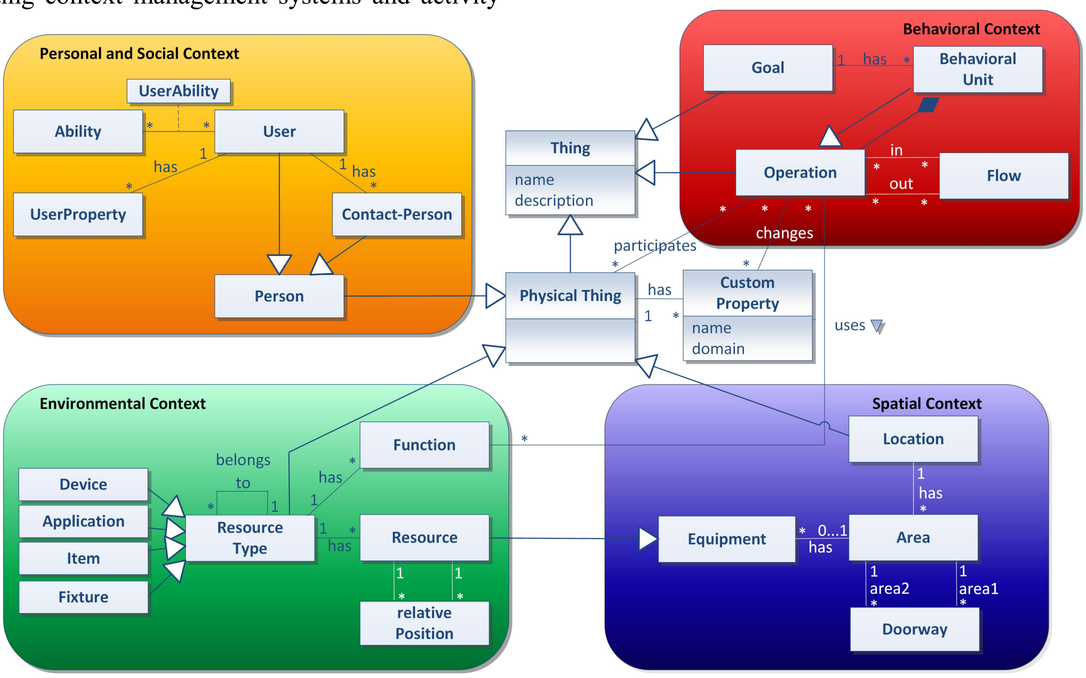

Fig. 1. HCM-L meta-model (excerpt)

To reduce these deficits and to improve the HBMS-System and its setup process this paper is focused on:

a) *Semantic manuals*: Information about the structure and handling of a device or application represents domain knowledge. It is independent of a certain user and usually described by the manufacturer in form of a manual. We describe resources semantically including functions, problem situations, warnings and instructions in form of *semantic manuals* to make them *understandable* for the HBMS-System and *interoperable* with its environmental context model.

b) *Personalized and adaptive user clients*: Current activity recognition approaches are too coarse to monitor all needed details for the HBMS-System. We show how *personalized and adaptive HBMS user clients* and the power of the HBMS environmental context model can be used to *bridge* this *activity recognition gap*. We add a user client to the HBMS-System which interacts adaptively and smart with the user to find out if a proposed activity has been done (as an alternative user activity recognition service) and communicates the answer to the cognitive assistance system.

III. Related Work

This section summarizes the most relevant related work for us to join the cognitive assistance system HBMS-System with the semantic web to simplify the construction of inhabitant's behavior and context models and to improve its activity recognition capability.

A. Cognitive Assistance

Cognitive assistance intends to provide just-in-time activity guidance for people suffering from cognitive deficiencies in completing their activities. A smart home is a residential home setting augmented with a diversity of multimodal sensors, actuators, and devices where this cognitive assistance can be given based on ICT services and systems. By monitoring environmental changes and inhabitant's activities, an assistive system can process perceived sensor data, make timely decisions, and take appropriate actions to assist an inhabitant to perform activities, thus extending the period of time living independently within their own home environment. In their survey, [1] summarize the most recent smart home projects, they give a classification of the main activities considered in smart home scenarios and review the different types of sensors that can be used to monitor these activities. In general to achieve this objective, a bottom up, sensor centric approach is used covering the following levels:

(1) *Monitoring*: Sensors monitor an inhabitant's behavior and their situated environment in real time and dynamically fuse and interpret the multiple modalities of signals. To monitor inhabitant's behavior and environmental changes visual/audial sensing facilities and networked sensor technologies can be used. Sensors can be attached to an actor under investigation (wearable sensing) for recognizing physical movements or to objects that constitute the activity environment (dense sensing) for recognizing human-object interactions [1].

(2) *Activity Recognition*: Infer and recognize inhabitant's activities, changes or anomalies, continuously in real time in a progressive way based on activity models. To recognize inhabitant's activities, data driven and knowledge driven approaches are applied. Data driven approaches require large datasets for training activity models and it is difficult to apply learning results from one person to another. Knowledge driven approaches use domain knowledge and are generally logical or ontological in nature. But also latter show some issues [9] like lacking accuracy and robustness of recognized activities, the need for a large number of sensors, low reusability or complex modeling languages. [1] summarizes activity recognition approaches in correspondence with relevant sensors and monitored activities.

(3) *Assistance*: Provide assistance to help the inhabitant perform the intended activity based on recognized activities.

[12] moves from a sensor centric approach for activity recognition to a top-down approach for *intention recognition*, where the inhabitant's intended goals are the focus of the assistance system. Beliefs, Desires and Intentions (BDI) are modeled from an abstraction of human cognition and this approach combines *intent recognition* with *action planning mechanism* in form of an assistive intelligent agent. HBMS-System applies this approach too.

B. Semantic Mark-up and Web Ontologies

The semantic web offers a large variety of technologies for semantic data enrichment and semantic interoperability [13]. Several vocabularies/ontologies for marking-up things on the web exist in a large range of domains. It did not make sense for us to create a 'resource' ontology independently of any other existing ontology as the success of solutions using shared, distributed knowledge depends on the ability to share and reuse existing ontologies [14]. Using Linked Open Vocabularies (LOV) catalogue [15] we investigated those ones, which seemed to be most promising to mark-up resources, their functionality and their manuals [16]. Schema.org resulted as the most suitable candidate. Schema.org provides a single schema for structured data on the Web and its vocabulary includes a large variety of domains [17]. Schema.org was created by Google, Microsoft, Yahoo and Yandex in 2011. Today it is applied widely and continues to develop, e.g. goodRelations [18] and other accepted domain ontologies have been integrated or are hosted at schema.org.

Schema.org offers community extension mechanisms as a way of adding more detailed descriptive vocabulary that builds on the schema.org core. There are two kinds of extensions: reviewed/hosted extensions and external extensions. Both kinds of extensions typically add subclasses and properties to the core. Properties may be added to existing and/or new classes[2]. It can be used with different encodings, including RDFa, Microdata and JSON-LD. Furthermore, there exists a RDF term-mapping, and data-entry validity can be easily tested by tools like the Google Structured Data Testing Tool[3] and others. This ensures accurate entry and converti-

[2] See schema.org Extensions. URL: goo.gl/qT0M5b

[3] see: http://goo.gl/qEW9In

bility, which speak in favor of schema.org remaining a major player in the metadata industry.

IV. Semantically enriched Manuals

Manufacturers provide manuals to inform an user how to prepare, use, transport, store and maintain resources. These manuals are typically described in form of multipage, multilingual, detailed documents, made available for the user by hardcopy or online. Sometimes videos on social media channels are provided explaining the handling.

Usually users become familiar with the main features of a resource on their own or in trainings and reread the manual later on or in detail, if needed. Latter is necessary if tool functionalities are used *infrequently* or the user shows *cognitive impairments*. *Renewed or replaced resources* force the user to adapt the tool handling knowledge. Locating support information within a manual and also using online manuals takes time, requires a certain computer literacy, interrupts and interferes user's activity and sometimes overcharges the user. At this point a cognitive assistance system could support context sensitively *how to use the resource*. Thus, the detailed information contained in manuals and the ability to semantically understand them is very valuable for active user assistance.

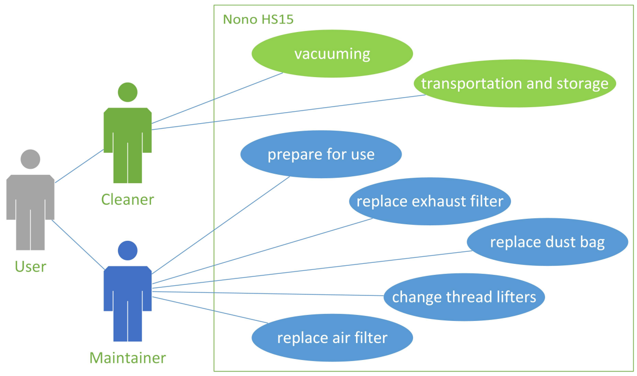

Fig. 2. Use Case Diagram 'Nono HS15'

While human readers understand the handling of a good manual mostly at a glance, an assistive system needs extra information to *comprehend* resources, their functionality and associated using instructions *semantically*. Although users are most widely interested in resource's core functionalities to support them in their activities, also 'support' functions (installation, maintenance) have to be carried out and described in manuals. Fig. 2 shows a use case diagram sketching functionality of a vacuum cleaner of type 'Nono HS15' (brand changed by the authors; for details see[4]). A user of 'Nono HS15' can act in two roles: (1) as a 'Cleaner', using the resource to execute their cleaning activities and (2) as a 'Maintainer' to prepare and keep the resource operational.

After having examined several manuals and bearing our environmental context model (see Fig. 1) in mind, we figured out the needed information for manual's semantic comprehension and modeled resources, their functionality and associated using instructions at the meta-level. As brought up in section 3 we aimed to reuse schema.org as far as possible. Furthermore, we used extension mechanisms of schema.org.

Fig. 3 sketches the result of this process and focuses on those schema.org classes and properties, which are suitable for this purpose. In the following we focus on the identified existing and extended schema.org classes and properties (e.g. *Product* instead of http://schema.org/Product) to mark-up resources and their handling and map them also to the **environmental context elements** of HCM-L from Fig 1 for interoperability purposes.

As the e-commerce schema from the goodRelations project has been integrated into schema.org in 2012, it is easy to express structured data about products and related facts with schema.org vocabulary. Thus, **Resource** can be easily mapped to *Product*, with the properties name, description, identifier, category and image. For the specialization of a product into different models, schema.org offers the subclass *ProductModel* and the property *successorOf* to tag developments of a product over time. **Component** (if a **Resource belongs to** another **Resource**) can be mapped to *Product* as well, as it includes a property *isAccessoryOrSparePartFor* refering to another product (or multiple products) for which this product is an accessory or spare part.

Actions were introduced in schema.org to describe the ability to perform a certain operation on a *Thing*. Every *Thing* and thus, also *Product* can have a set of *potentialAction* of type *Action*. This property references an idealized action in which this thing would play an 'object' role. There exist many action subclasses and *useAction* seems to be well suited for tagging **Core Functions**. A fitting *Action* subclass to map **Support Functions** has not been defined yet. Thus, a specialization of *Action* to *maintainAction* would be helpful to tag them.

Manuals can be considered as creative work. Schema.org offers *CreativeWork* with a lot of subclasses to tag web content like *Article*, *Book*, *MediaObject*, *Movie*, *Recipe*, *Website* and more. Although no schema.org subclasses for manuals have been defined yet, *TechArticle*, a subclass of *Article*, can be used to map **Instruction**, **Instruction Step**, **Warning** and **Problem Situation**. Thus, a specialization of *TechArticle* into *Instruction*, *InstructionStep*, *Warning* and *ProblemSituation* and the extension of *Instruction* with the property *steps* does make sense using *additionalType*[5]. The existing property *hasPart* (inverse property *isPartOf*) allows to indicate other CreativeWorks that are parts of this *CreativeWork*, so it allows to map the interrelationship between *ProblemSituation*, *Instruction* and *Warning*.

TechArticle offers the demanded properties *articleBody*, *articleSection* and *inLanguage*. Also prerequisites needed to fulfil steps and the proficiency can be described using the property *dependencies* and *proficiencyLevel*. The property *articleSection* can be used to distinguish the content tagged as TechArticle (e.g. articleSection:"Warning").

[4] Manual see: http://goo.gl/dHhvGA

[5] see e.g. http://sdo-schemaorgae.appspot.com/TechArticle

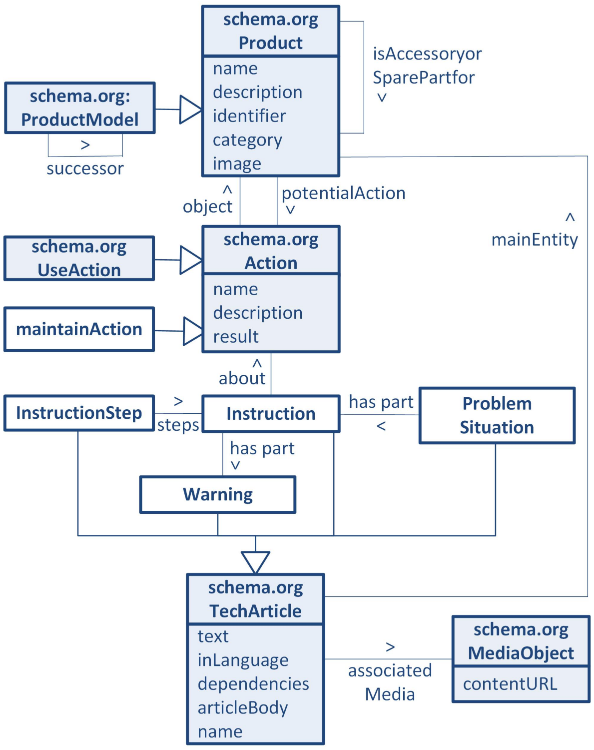

Fig. 3. Schema.org excerpt (colored fields) and our extensions (white)

MediaObject and more specific types like *AudioObject*, *VideoObject* and *ImageObject* can be associated to *TechArticle* using the property *associatedMedia*. As every *CreativeWork* can have a subject matter of the content using the property *mainEntity* (alternatively property *about*), this property can be used to assign it to a *Product* or *Action* tagged before (reverse property: *MainEntityOfPage*).

Online manuals tagged using schema.org this way would be a valuable and interoperable source of resource domain knowledge for the HBMS-System. The HBMS-System is only one possible application demanding for semantically enriched manuals. Clearly, semantic manuals can be exploited by *different applications* and *digital services* like *function based product comparison platforms* or *enhanced product search engines* (see Fig. 4).

V. Semantic Manual Integration and Use in the HBMS-System

This section explains the integration of semantic manuals marked-up as explained in section IV into the HBMS-System in more detail and demonstrates, what this information is used for during active assistance using the vacuum cleaner example. As we see in Fig. 4, the assumption for the following example is, that manufacturers marked-up the manuals of their resources (e.g. Nono HS15) online using schema.org and our extension.

During *HBMS-System setup and customization* the user context has to be defined (see section II). As mentioned, the resource definition and update of the environmental context is a considerable effort we wanted to reduce. Thus, the semantic interoperability between online manuals and the HBMS-System environmental context highly facilitates this process.

Semantic manual data (e.g. of Nono HS15) is collected from the web, transformed and integrated into the HBMS-System data stores and later on used for user support. The HCM-L Modeler enables to visualize the imported information in HCM-L, the domain specific modeling language of HBMS.

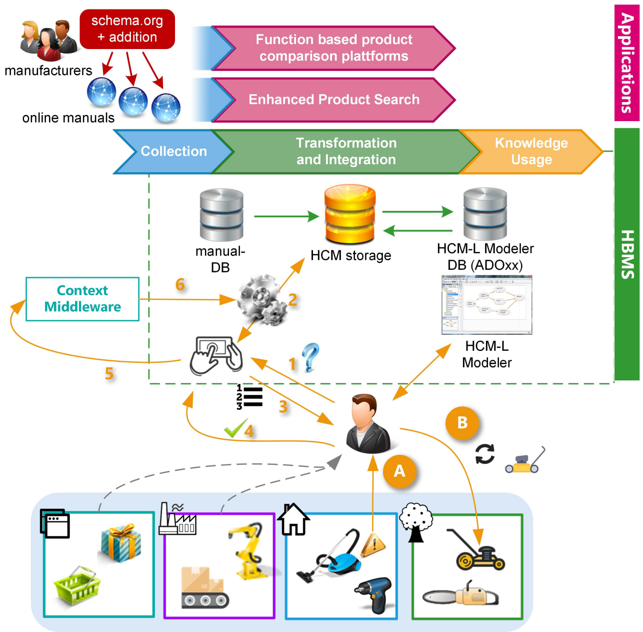

Fig. 4. Semantic manuals in the HBMS-System

During the *HBMS-support process*, the user is guided on demand through *behavioral units (BUs)* and their *operations*. These BUs can be in- or out-door, at home or in business.

If one operation of a BU includes the use of a *special device functionality* or gives a *warning* (e.g. (A) in Fig. 4, dust bag of Nono HS15 has to be replaced), (1) the user contacts the HBMS-System, which (2) takes the imported knowledge regarding Nono HS15 and (3) passes the appropriate information via a client (e.g. a tablet or a voice control system) to instruct the user step by step. After each instruction step, (4) the user feedbacks the HBMS-System about the current execution status (e.g. via click or voice acknowledgement). The HBMS-System (5) simulates sensor data based on this user feedback and feeds the data about the user activity back into the related context middleware. From the point of view of this middleware, it seems as if the data comes from a genuine sensor. Thus, (6) activity data is handled by the HBMS-System as well as if it were recognized via a real sensor. It is included in the HBMS knowledge base and used in succeeding operations. (2) to (6) are now repeated until the problem is solved and the warning is gone.

Moreover, an automated mapping from old to renewed devices is possible. If a device is replaced by a new one or a new device is added (e.g. (B) in Fig. 4), the update of the manual goes the same 'collection, transformation, integration' way until the manual information is in the knowledge base and can be used for support.

VI. Conclusion and Open Challenges

This paper showed an approach to *mark-up online manuals* to *semantically describe* resources like devices and appliances, their functionality and associated using instructions. This makes them *understandable* for the HBMS-System (and others) and *interoperable* with its environmental context model. We proposed to use schema.org and defined as well a vocabulary subset and a small extension of schema.org in form of a meta-model. We showed how *personalized and adaptive HBMS user clients* and the power of the *HBMS environmental context* model can be used to *bridge* an existing *activity recognition gap*.

Currently we are working on the *realization* of the collection, transformation and integration process in the HBMS-System. Another important issue is to raise our extension to at least a *hosted schema.org extension*.

Although we used with 'Nono HS15' an appliance example, the idea of semantic manuals is *transferable* to other domains like software applications or machines in production halls and their manuals too. Describing industrial information models with ontologies and constraints is an occurring research topic [19]. To provide active assistance for such processes in the industrial context (e.g., for manufacturing processes) semantic mark-ups of *industrial manuals* are a promising approach. In addition, *software applications* could benefit from semantic manuals. Consequently, further development of the HBMS-System will *focus on these domains*.

Nevertheless, the *tagging of manuals* with schema.org and our extension *without tool support* is a remaining challenge. Suitable *tools* are needed, to make it easier for manufacturers to *create structured manual data*. A natural language approach, *generating* the required structured metadata *out of text documents* in the web, will be helpful for manufacturers and is another interesting research direction.

Furthermore, the *Internet of Things (IoT)* world offers a large variety of open issues for the research community. Approaches for *supporting interoperability using ontologies* are among them [20]. Working with heterogeneous smart systems in assistive systems is still a challenge, where the use of ontologies for standardization and support of semantic interoperability would provide a *large benefit* for current projects. Moreover, *ontology grounding* of the HBMS-meta-model in a foundational ontology [21] is intended by the research team, to improve the *quality* of conceptual modelling languages and models.

References

[1] Q. Ni, A.B. García Hernando, and I. Pau de la Cruz, "The elderly's independent living in smart homes: A characterization of activities and sensing infrastructure survey to facilitate services development" Sensors, vol 15.5, pp. 11312-11362, 2015.

[2] J. Michael, and H.C. Mayr, "Conceptual Modeling for Ambient Assistance" in W. Ng, V.C. Storey, and J. Trujillo (eds.) Conceptual Modeling - ER 2013, Springer, pp. 403-413, 2013.

[3] S. Russel, and P. Norvig, "Artificial Intelligence - A Modern Approach" Pearson Education, 2014.

[4] J. Michael, "Kognitive Modellierung für Assistenzsysteme", Doctoral Thesis, Alpen-Adria-Universität Klagenfurt, 2014

[5] J. Michael, and C. Steinberger, "Context Modelling for Active Assistance" ER Forum 2017, CEUR, 2017, in press

[6] H.C. Mayr, J. Michael, S. Ranasinghe, V. Shekhovtsov, and C. Steinberger, "Model Centered Architecture" in Cabot et al. (eds.) Conceptual Modeling Perspectives, Springer, 2017

[7] A. Rao, and M. Georgeff, "BDI Agents: From Theory to Practice", in ICMAS 1995, vol. 95, pp. 312-319, 1995.

[8] F. Al Machot, H.C. Mayr, and J. Michael, "Behavior Modeling and Reasoning for Ambient Support: HCM-L Modeler" in M. Ali, J.S. Pan, S.M. Chen, and M.F. Horng (eds) Modern Advances in Applied Intelligence. IEA/AIE 2014. LNCS, vol 8482, Springer, 2014.

[9] L. Chen, C.D. Nugent, and H. Wang, "A knowledge-driven approach to activity recognition in smart homes" IEEE Trans. on Knowledge and Data Engineering, vol 24.6, pp. 961-974, 2012.

[10] H.C. Mayr, F. Al Machot, J. Michael, G. Morak, S. Ranasinghe, V. Shekhovtsov, and C. Steinberger, "HCM-L: Domain-Specific Modeling for Active and Assisted Living" in D. Karagiannis, H.C. Mayr, and J. Mylopoulos (eds.) Domain-specific conceptual modeling. Concepts, methods and tools, pp. 527-552. Springer, 2016

[11] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of things: A survey on enabling technologies, protocols, and applications" *IEEE Communications Surveys & Tutorials*, vol 17(4), pp. 2347-2376, 2015.

[12] J. Rafferty, C.D. Nugent, J. Liu, and L. Chen, "From activity recognition to intention recognition for assisted living within smart homes" IEEE Tr. on Human-Machine Systems, vol 47(3), pp. 368-379, 2017.

[13] L.M. Chan, and M.L. Zeng, "Metadata Interoperability and Standardization-A Study of Methodology Part I: Achieving Interoperability at the Schema Level" D-LIB Magazine, vol 12(6), 2006.

[14] O. Corcho, M. Fernández-López, and A. Gómez-Pérez, "Ontological Engineering: Principles, Methods, Tools and Languages" in C. Calero, F. Ruiz, and M. Piattini (eds.) Ontologies for Software Engineering and Software Technology, Springer, 2006.

[15] P. Y. Vandenbussche, G.A. Atemezing, M. Poveda-Villalón, and B. Vatant, "Linked Open Vocabularies (LOV): a gateway to reusable semantic vocabularies on the Web" Semantic Web, vol 8(3), pp. 437-452, 2017.

[16] C. Steinberger, and J. Michael, "Semantic Mark-Up of Operating Instructions" tech. report, URL: https://goo.gl/apZDwP, 2017

[17] R.V. Guha, D. Brickley, and S. Macbeth "Schema. org: Evolution of structured data on the web." *Communications of the ACM,* vol 59.2, pp. 44-51, 2016.

[18] M. Hepp, "GoodRelations: An Ontology for Describing Products and Services Offers on the Web" in A. Gangemi, and J. Euzenat (eds.) Knowledge Engineering: Practice and Patterns, 5268, pp. 329-346. Springer, 2008.

[19] E. Kharlamov, et al., "Capturing Industrial Information Models with Ontologies and Constraints" in P. Groth et al. (eds.) The Semantic Web - ISWC 2016, LNCS 9982, pp. 325-343, Springer, 2016.

[20] L. Daniele, M. Solanki, F. den Hartog, and J. Roes," Interoperability for Smart Appliances in the IoT World" in P. Groth et al. (eds.) The Semantic Web - ISWC 2016, LNCS 9982, pp. 21-29. Springer, 2016.

[21] G. Guizzardi, R. Falbo, and R.S. Guizzardi, "Grounding Software Domain Ontologies in the Unified Foundational Ontology (UFO): The case of the ODE Software Process Ontology" in M. Lencastre et al. (eds.) 11th Iberoamerican Workshop on RE and SW Environments, pp. 127-140, 2008.