Integrated Search for Wearable Devices and Physical Properties

Mareike Kritzler
Siemens Corporate Technology
Berkeley, CA 94704, USA
mareike.kritzler@siemens.com

Jack Hodges
Siemens Corporate Technology
Berkeley, CA 94704, USA
jack.hodges@siemens.com

Florian Michahelles
Siemens Corporate Technology
Berkeley, CA 94704, USA
florian.michahelles@siemens.com

Abstract
This paper presents a search tool for commercially available wearables that seeks to demonstrate the real-world value of linking existing physical property models and repositories with wearable device models and repositories. Integrating these models is necessary in order to provide undifferentiated access to individuals who need to search in a faceted manner through different models. As an example use case a semantic model of wearable devices is integrated with existing semantic models for sensors, physical properties, and medical information (diseases, symptoms, anatomy) in order to provide a means for medical professionals to identify, select, and recommend wearable devices for individuals under various medical scenarios.

Author Keywords
Wearable Devices; Quantified Self; Ontologies; Semantic Integration and Search

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
Research on self-knowledge through self-tracking has become a growing topic of interest for individuals that are interested in personal analytics. Technological progress and

development of wearable sensors allow individuals that wish to quantify themselves to collect their physiological data 24/7. It allows quantified users to gain access to data which is acquired during those individuals' daily lives. A large number of wearable devices containing different sensors are available for data acquisition, e.g., Apple Watch, Samsung Gear, Fit Bit, and many more (see Vandrico[1] webpage for a current list). Some early adopters of such technologies wear several of these devices to continuously track their daily activities, body conditions and overall performance. Despite the plethora of devices available, there is a lack of tools that support the selection of wearable devices for a certain tracking goal. No structured process is available that can match an individual and measurement type to a device.

Collected data regarding body functions is not only interesting for the quantified individuals themselves but may also be useful in a professional healthcare context. Consider a physician that has a patient diagnosed with Type II Diabetes. How might this physician locate wearable devices that could aid in tracking the patient's physical condition? Currently they would have to enumerate the symptoms associated with Diabetes, associate those with the kinds of measurements needed to qualify/quantify the symptom, and then search for wearable devices capable of measuring that quantity. Access to this kind of information would require multiple searches in different repositories/sources and would require time and effort far exceeding an integrated search environment. Using a semantic integration, it may be possible to do all this in a single application.

This paper describes a tool that allows for the search of wearable devices through different connected repositories and thus provides the medical professional direct access to multiple sources of information in a single application. The value of semantic integration is demonstrated by showing how medical professionals could benefit by having integrated access to bio-medical models and repositories that also integrate with wearable devices and the properties they measure. This approach could be used by medical professionals who are working with patients that need to monitor their medical conditions, especially chronic diseases such as diabetes. Doctors would use this tool in order to select a wearable device that collects data about a diagnosed disease or symptom and suits the patients' needs. This approach is readily transferred to other fields outside of the medical domain.

[1] See: http://www.vandrico.com/wearables

Related Work

Integrating information in disparate models doesn't happen by itself and is an area of active research. One approach to integrating information models is to build "bridges" between them. Maedche et al [5] used the notion of a semantic bridge to map ontologies. This same approach was used in the current study to link the DOID, SYMP, FMA, QUDT, and SSN ontologies without impacting the original ontologies or their repositories. Bozic, et al [1], demonstrated the use of semantic bridges with aspects of SSN and time-series climate change data.

Manual ontology data mapping requires sophisticated language understanding skills and subject matter expertise. Rance, et al [8] demonstrated a semi-automated approach could be used for data mapping. They sought to show a mapping between two specialized data sources for rare diseases (i.e., the Office of Rare Diseases Research - ORDR, and Orphanet), using the Unified Medical Language System (UMLS) as the mapping pivot. They used the online Mendelian Inheritance in Man (OMIM) model as the reference. They used syntactic filters to normalize the data

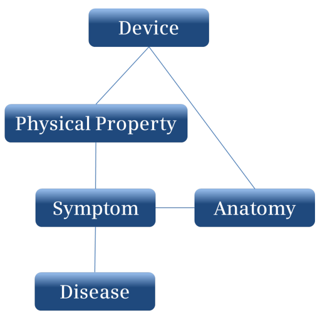

Figure 1: Targeted integration of five information types

Diseases →	symptoms
Symptoms →	anatomy
Symptoms →	properties
Wearables →	quantities
Wearables →	anatomy

Table 1: Functional dependencies between models.

source results to match against the UMLS and OMIM data. Although Rance, et al, demonstrated an automatic mapping in 79%-95% of the cases (ORDR vs. Orphanet, respectively) it is clear that an automated approach can be used to reduce the amount of work needed by, but cannot entirely replace, the subject matter expert.

Approach

Overall, semantic models are developed for public consumption but are not integrated for general use. Integration of wearable sensors into this framework of ontologies, taxonomies, and repositories is performed by creating or extending models along semantic or graph boundaries using knowledge of the associated models and domains. Mappings between the ontologies, taxonomies, and repositories are thus constructed.

Figure 1 shows five information types that need to be integrated to support the diabetes diagnosis to device recommendation scenario described in this paper. The integration of biomedical information is useful in helping medical professionals evaluate and select wearable devices for patients: (1) human diseases, (2) disease symptoms, and (3) human gross anatomy. For the physician, being able to diagnose a patient, and relate the associated disease or symptoms with associated anatomy, would allow multiple access points to integrate with wearable devices. Symptoms are associated with physical properties (e.g., cardiac disease and blood pressure), so integrating symptom models with properties that a wearable device might measure is necessary. In order to integrate the wearable device to the biomedical models, both the anatomical parts where the device is worn and the properties that it measures are needed. To be truly versatile and effective, all selected semantic models have to be integrated through property alignment into (effectively) a single model and searched from multiple entry points in a single interface. Only in this way can a user navigate from any starting point to any end point at will. These alignments are based on functional dependencies between the models (see Table 1).

Figure 2 shows the integration of the various curated models, taxonomies, and repositories used in this paper for a particular search (here Type II Diabetes). The rounded rectangles refer to models, the cylinders to repositories of taxonomies and data and white rectangles to instances of those repositories. Solid lines between the repositories represent the ontological alignments. The large dotted line shows one path (disease → symptom → property → device) a search might take through these models to relate Type II Diabetes to a wearable device capable of measuring heart rate/blood pressure for the symptom abnormal weight gain.

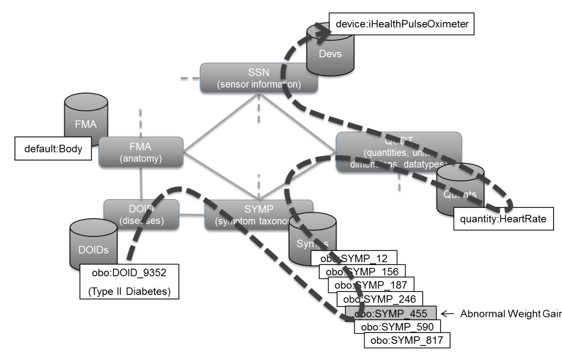

Figure 2: Integration of 5 ontologies and sample graph traversal

Implementation - Wearable Search Tool

An implementation of the proposed wearable search tool shows how multiple biomedical models and repositories can be integrated to provide value to a health care professional. Figure 3 shows the landing page that is used as an entry point for a medical professional, with starting points articulated with imagery denoting the type of entry point and the type of information associated with the entry point. For example, a physician might be interested in the relationship between symptoms and physical properties as they relate to wearable devices, so they might enter from the upper left portion of this figure. This landing page provides an overview of the five used models and repositories. Each one of them is a possible entry point for a search on the landing page.

The concept of a symptom or a disease was talked about in the approach section. Now we talk about the specific model repositories that are used for the implementation of the wearable search tool. The choice of ontologies used in this study is based on the goal of demonstrating an integrated value. Three ontologies from the Open Biological and Biomedical Ontologies (OBO) Foundry ontologies are selected due to the content they modeled as well as the fact that they have unique identifiers that allow them to be cross referenced. Disease information is represented using the OBO Disease Ontology (DOID) [9], symptom information is represented using the OBO Symptoms Ontology (SYMP) [10], and anatomical information is represented using the OBO Foundation Model of Anatomy (FMA) ontology [6] [2] are used. The QUDT[2] models are used because they represent an integrated approach to quantities, units, dimensions, and datatypes, but other models exist that might have been used, such as the Model Library for Quantities, Units, Dimensions, and Values (QUDV) [7], or the Library for Quantity Kinds and Units (QU)[11]. QUDT is deemed to be the more comprehensive set of models, as it has representations for biomedical quantities needed to model wearable devices. The Semantic Sensor Network (SSN) [3] ontology is an emerging standard for device sensor modeling and provideds a good integration point for the project.

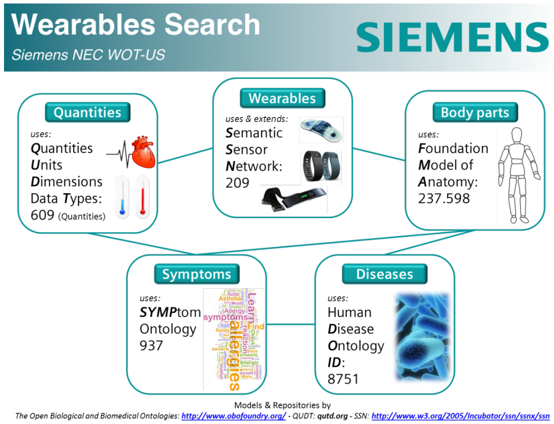

Figure 3: Landing page with five sample entry points to the wearable search tool

- Body Parts: are represented via FMA - it comprises an ontology and a taxonomy, and with nearly 240,000 instances.
- Wearable Devices: SSN ontology is chosen to model wearable devices - it has approximately 210 devices.
- Physical Properties: QUDT models are used for physical properties - it is comprised of about 600 quantity kinds.
- Symptoms: SYMP is used for symptoms and has 900 classes.
- Diseases: DOID is the basis for the integration and comprises an ontology and nearly 9,000 classes.

[2] All available through the Open Biological and Biomedical Ontologies Foundry

Three facets in the Semantic Search window:

- Body Parts: is where the wearable is worn
- Sensor Measurements: describes what properties the device can measure
- Symptoms: are those that can be detected with the device

Figure 4: Screenshot of devices search interface

Figure 4 shows a screenshot of the search interface. In this figure, a hierarchical decomposition of the entry point item is provided on the left. As an example, wearable devices are selected as an entry point for a search. The browser view shows all of the devices available in the repository on the left side of the tool. A faceted search area is shown in the center which allows the medical professional to select constraining filters on related characteristics. There are three facets shown in the Semantic Search window by default (see on the left).

For example, the professional might be interested in looking for wearable devices that attach to the arm and that measure heart rate. The right hand side provides the list of devices that meet these requirements. Selecting one of these items provides a view of the device and all of its connections to other models/data in the environment. This same approach is applied along any of the dimensions supported by this tool.

If, for example, Heart Rate is selected under the Sensor Measurement facet, it is shown that there are many wearable devices that can be used to measure cardiac function. The search can be restricted further by selecting a body part. For example, restrict the result to those devices worn on the finger. This search results in one device. The detailed view (see Figure 5) shows all of the information about this particular wearable device, most of which are links to other model information:

- Where it is worn on the body.
- What symptoms it is associated with through measurement.
- What company manufactures the device.
- The device URL.
- What other sensors are on the device.
- What properties the device measures. Each of these properties point to other structured information.

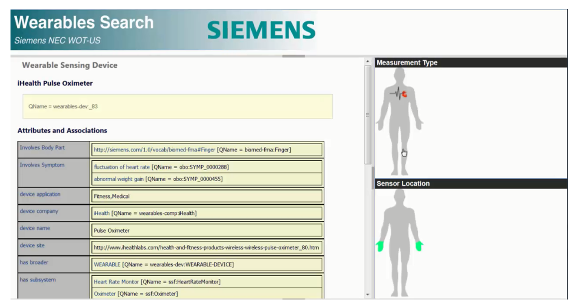

Figure 5: Screenshot of device detail view including device placement and measurement

The view also provides an image representing where on the body the device is worn. Since devices worn on the finger were selected in this example, the finger location is highlighted on the diagram. The view also shows an image representing what the device measures. In this case, the device measures heart rate and blood pressure. It is possible to return to the landing page and enter from other semantic starting points, such as quantities, diseases, or body parts.

Conclusions and Future Work

The paper describes an integration of five curated ontologies for the purpose of demonstrating a semantic search of wearable devices for health care professionals in a real-world scenario. For this search, the properties of wearable devices are connected with symptoms, diseases, body parts, and quantities. The advantage of this approach is to support reuse of existing disparate models and repositories, and extend as needed. It allows for a search starting and ending at any other point (any connected repository) as though the users were navigating through an enterprise database. This approach allows a quantified self individual to select an appropriate device that matches one or more requirements.

Ontology choices were limited to those that used unique identifiers. Ontology alignment was achieved using single-property semantic bridge ontologies (DOID$\rightarrow$SYMP, SYMP$\rightarrow$FMA, SYMP$\rightarrow$QUDT, SSN$\rightarrow$QUDT, and SSN$\rightarrow$FMA. Manual unstructured text data mining was used to populate the bridge ontologies. Only four of the 9,000 diseases in DOID, twelve of the 1,000 symptoms in SYMP, thirty of the roughly 240,000 anatomical entries in FMA, and twenty of the 1,400 quantities in QUDT were used for the wearable search tool demo.

The production of a full-fledged demonstrator for wearable devices in the domain of professional health care requires that the mappings performed manually, described in this paper, for a few diseases, symptoms, etc. need to be fleshed out to the full ontologies. The approach would be to identify those properties that can be measured by wearable devices, map to the symptoms that can be associated with those properties, and then map to the anatomical parts and diseases that those symptoms are associated with. It would be appropriate to use semi-automated tools to achieve these mappings.

This paper describes the integration of only five models and repositories but it is possible to integrate even more information sources (such as insurance providers) in order to search through more categories. Also, it is possible to move away from the medical domain and search through wearables in a different domain. If wearables are interesting for workplace health and safety, OSHA see [4] requirements could be integrated in the search tool as well.

REFERENCES

1. B. Bozic, J. Peters-Anders, and G. Schimak. 2014. Ontology Mapping in Semantic Time Series Processing and Climate Change Prediction. In *International Environmental Modelling and Software Society (iEMSs), 7th Intl. Congress on Env. Modelling and Software*. D. Ames and N. Quinn and A. Rizzoli eds.

2. Ralph Hodgson. 2012. Quantities, Units, Dimensions, and Datatypes Ontologies.

3. L. Lefort, C. Henson, and K. Taylor. 2011. Semantic Sensor Network XG Final Report.

4. M. Baeckmann M. Kritzler, F. Michahelles and A. Tenfaelt. 2015. Wearable Technology as a Solution for Workplace Safety. In *14th International Conference on Mobile and Ubiquitous Multimedia (MUM 2015)*.

5. A. Maedche, B. Motik, N. Silva, and R. Volz. 2002. MAFRA - A MApping FRAmework for Distributed

Ontologies in the Semantic W. In *EKAW 2002, LNAI 2473*. A. Gomez-Perez and V.R. Benjamins eds, Springer-Verlag pubs, 235–250.

6. Onard Mejino. 2012. Foundational Model of Anatomy.
7. OMG. 2009. Model Library for Quanties, Units, Dimensions and Values (QUDV), Version 1.2. In *OMG Document ptc/2009-08-16, OMG Systems Modeling Language (OMG SysML)*.
8. B. Rance, M. Snyder, J. Lewis, and O. Bodenreider. 2013. Leveraging Terminological Resources for Mapping between Rare Disease Information Sources. In *Medinfo, C.U. Lehmann et al eds*. IMIA and IOS Press, 529–533.
9. Lynn Schriml. 2012a. DOID: The Human Disease Ontology.
10. Lynn Schriml. 2012b. SYMP: The Symptom Ontology.
11. W3C. 2005. Library for Quantity Kinds and Units: schema, based on QUDV model OMG SysML, Version 1.2.