Sensing Presence (PreSense) Ontology – User Modelling in the Semantic Sensor Web

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Abstract. Increasingly, people's digital identities are attached to, and expressed through, their mobile devices. At the same time digital sensors pervade smart environments in which people are immersed. This paper explores different perspectives in which users' modelling features can be expressed through the information obtained by their attached personal sensors. We introduce the `PreSense` Ontology, which is designed to assign meaning to sensors' observations in terms of user modelling features. We believe that the *Sensing Presence (`PreSense`)* Ontology is a first step toward the integration of user modelling and "smart environments". In order to motivate our work we present a scenario and demonstrate how the ontology could be applied in order to enable context-sensitive services.

Keywords: linked data streams, semantic sensor web, user modelling, smart objects

1 Introduction

Digital sensors have pervaded the modern world, and increasingly make up the majority of connected devices, in, e.g., intelligent buildings, traffic lights and in particular in mobile devices. These advances have resulted in "smart" environments, marking an evolution in the generation of information, and the interaction between humans, smart and ordinary devices and sensors. Human-computer interaction now extends to everyday objects attached to the end user or located in their changing environment [8]. Users produce data streams through their mobile devices, wearable and implantable microsensors (e.g., GPS tracklogs, heart rate monitors). These devices now frequently act as the gateway to cyberspace, which is increasingly becoming an extension of the lives of humans in the real, physical world. Therefore, these can provide information regarding a user's physical context (e.g. location, physiological state), in addition to their digital environment (e.g. adding new friends to an online social network, tweeting on an evolving event). This leads to a bond between the user and their mobile devices and sensors, in which the latter act as an extension of the user's identity, providing real-time information that can reveal important user and environmental characteristics.

This provides motivation to explore new techniques for combining current user modelling methods, that depict the digital identity of a given person, with sensor information distributed across the online and physical worlds.

The contributions of this paper are as follows: we explore different perspectives in which the attachment of sensor data to user models can impact the derivation of tailored services that feed into users' interaction with smart objects and environments, by providing real-time contextualisation. We propose the *Sensing Presence* (`PreSense`) ontology as an approach to modelling the attachment of sensor data streams to a user profile, allowing rich, semantic, real-time change in a user's representation. This enables also the integration of observable user features to the linked data cloud [3].

The paper is structured as follows: in section 2 we present the motivation for our work by discussing different perspectives on the use of sensor data for user modelling; in section 2.3 we introduce a scenario that highlights challenges and benefits that the attachment of sensor data to user profiling presents; section 3 discusses existing ontologies that consider sensor data in user modelling; in section 4 we introduce a set of requirements for modelling the attachment of sensor data streams to a user profile; in section 5 we introduce the Sensing Presence Ontology (`PreSense`). Section 6 describes the application of the ontology in relation to our scenario; finally, section 7 discusses the potential of this work, plans for evaluation, and concludes the paper.

2 Motivation

The relevance of users to the Sensor Web has been explored from the perspective of users acting as collective sources of information. Goodchild [9] highlights the relevance of the Social Web in Volunteered Geographic Information, where users have created a mesh of global information. Projects like SensorBase[1] and SensorPedia[2] provide a platform for sharing online sensor information within user communities. However, little attention has been paid to the importance of users' sensors as gateways for personal feature information. This section motivates our work by introducing different perspectives from which users engage with the physical and online worlds through sensor data.

2.1 Mobility in the Digital Society

In the past few years, users' online activities, including web browsing, online shopping, and social web media use [15,20], have served as information sources for user modelling. Further, the emergence of compelling social web platforms (e.g. Facebook[3], Twitter[4]) have encouraged users to proactively participate, shaping their online personae and influencing their perception about how they are viewed by others (a.o., [23]).

Social studies on the adaptation of users to online technologies highlight that users appropriate telecommunications technologies in ways that fit their social groups, life stages, sociability and activities [10]. Since mobility has become a central aspect of the digital society, the introduction of location-aware services in social web platforms for mobile devices has received considerable attention from researchers in recent years. Research in this area includes scenarios for emergency response, tracking, navigation,

[1] `http://sensorbase.org`
[2] `http://www.sensorpedia.com`
[3] `http://www.facebook.com`
[4] `http://twitter.com`

billing and social networking [16,21,27]. Part of the success of these applications is the user's increased dependency on mobile devices; which have become, for some, an indispensable tool. While the use of sensors for registering users' features (e.g. location) has proved to be fundamental in these applications, transient, sensor-based information has, to date, not been considered as an inherent component in user modelling.

2.2 Sensors and Users' Context

Sensors refer not only to physical sensor devices but also to values computed as a result of the composition of indirect or abstract measurements derived from multiple, distributed, often heterogeneous data streams [5,19,24]. Such sensors are usually referred to as *virtual sensors*; they allow the abstraction of data collection away from a fixed set of physical objects. A virtual sensor may define a number of valid sources of information, allowing it to poll for and retrieve information from different sources and at varying levels of granularity.

Following this definition, we consider a *web-based sensor* as an extension of the concept of virtual sensors, in which the measuring computation involves data streams generated from web resources. A web-based actuator may be regarded as a reactive computation that produces a response to a specified event. E.g. NASA Hurricane[5] on Twitter is a data stream of instantly updated information generated from the continuous monitoring of different devices sensing meteorological conditions for predicting hurricanes and tropical cyclones all over the world.

In the same way, personal data streams may be regarded as gateways reporting relevant information for user modelling. The information embedded in these streams involves different users' context. User context is built on static, stable and dynamic contexts. A user's static and stable contexts represent information about or related to a user that does not, or rarely, changes in time, e.g. the relation between a user and their hometown or work place. A user's dynamic context, in contrast, reflects highly changing information, which is often influenced by the environment in which a user is immersed; this includes, e.g., changes in position, anxiety levels while in a traffic jam.

Advances in intelligent, context-aware systems promote a vision of increasingly autonomous and ubiquitous applications that act on proactive knowledge to provide tailored services to individuals. These smart systems must not only support users in static, pre-defined environments, but also adapt to users' changing context and evolving goals. However, the integration of user context and the user's immersed environmental context, taking into account tempo-spatial restrictions, still requires research. We present next a scenario highlighting the role of sensor data streams in a user profile.

2.3 Scenario

Imagine Alice, a *Doctor* working at a public hospital, and Bob, a *Patient* suffering from Type II diabetes and obesity. Bob's treatment combines regular insulin injections with a diet plan. His nutritionist works with Alice to monitor how well he follows the plan, his physical activity and the impact both have on his overall health. Periodic reviews will

[5] NASAHurricane: `http://twitter.com/NASAHurricane`

take this information into account in updating his treatment. Alice must also monitor Bob's blood glucose levels, to determine the suitability of both his diet and medication.

This scenario requires Bob to wear multiple sensors that communicate with Alice over a network. More precisely, it requires the attachment of sensor information to Bob's personal attributes. Given the emergence of sensor-enabled mobile devices, we can imagine that Bob owns a device that connects to the Internet and monitors his location and health [4,7]. In this context, Alice accesses, in real-time, the data generated by Bob's sensors. Should Bob's blood sugar reach a dangerous level, Alice must be able to dispatch emergency assistance to Bob in the most efficient way. Information on his diet is not critical, so is only uploaded periodically.

Let us consider a weekday when Bob is returning to his office after inspecting a construction site with a client. His sensors have recorded higher than usual physical activity and that he missed his usual mid-morning snack. His smartphone warns him of the danger of his blood glucose levels dropping too low. Since it is close to lunchtime his nutrition monitor (NutrApp) polls for suitable eateries between his current location and his office (see Fig. 1**A**). It also checks Bob's online social network for recommendations by friends he often eats out with. The NutrApp polls for the ingredients of meals and portion sizes from virtual sensors, and determines suitability by matching with the requirements of his diet plan. Time to cook is also important – his calendar has posted a reminder about an early afternoon meeting he must prepare for (Fig. 1**B**). By merging online information with GPS the NutrApp will try to locate members of Bob's social network in the neighbourhood, whose calendars or status information show they are available – if any are found Bob will receive a suggestion to invite them to join him.

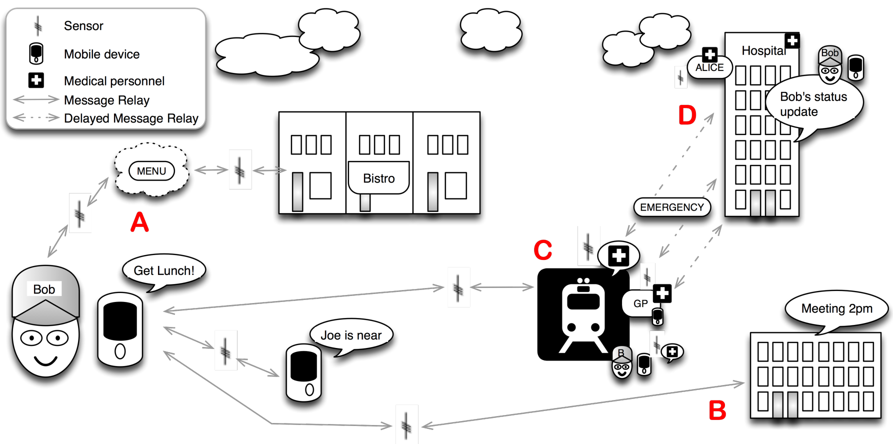

Fig. 1. Schematic for the `PreSense` scenario, illustrating the exchange of data streams between sensors, and the interaction between human actors and other entities as a result.

To illustrate an emergency in which situational context is communicated to external actors via sensors, let us consider what happens if Bob ignores the alerts he receives to stop for lunch, because he forgot to carry his medication. He decides to return directly to his office, 45 minutes away via the subway. However, due to a signal failure Bob's train is held stationary just outside a station 1 hour later (Fig. 1**C**). The stressful situation, combined with more exercise than normal and the time since his last meal, result in a large drop in his blood sugar. Without the sensors recording Bob's blood sugar he may not recognise symptoms of hypoglycaemia till they become severe. In our scenario his smartphone warns him to consume food or drink with high sugar content urgently. His sensors attempt to warn Alice when his blood sugar reaches a critical threshold; however with the train stuck in a tunnel Bob's sensors are unable to connect to Alice's.

Bob's sensors also attempt to locate nearby resources that can help to alleviate his symptoms. A *General Practitioner* (GP) in the next carriage receives the emergency alert. Virtual sensors apply a context-sensitive filter to Bob's medical information (some of which is held on his personal devices). Another virtual sensor calculates Bob's location using GPS and a schematic of the train and transmits this to the GP's mobile device over a (local) wireless network. The GP locates Bob, and armed with the information needed to attend to the semi-conscious patient, successfully handles the emergency.

When the train exits the tunnel the delayed emergency alert is relayed to Alice (Fig. 1**D**), with a timestamp that indicates that it has now expired. An update with more current, valid information on Bob's status is also relayed to Alice over the Internet.

To be effective, this scenario implies the need to connect different information streaming sources in time- and location-constrained situations, via (context-sensitive) virtual sensors. Particularly, it illustrates the demands of attaching streaming information to real world entities such as people – the GP must be able to identify the patient via sensor stream ownership. Wireless networks also play a role in information exchange; in the emergency situation this is how the virtual and physical sensors communicate.

3 Related Work

Ontologies for user modelling follow two paradigms: standardisation- and mediation-based modelling [26]. The first is based on a top-down approach in which ontologies for user modelling are designed to be domain-independent (top-level ontologies), or still high-level but domain-specific (upper ontologies) in order to be reusable by multiple systems. The second is a bottom-up approach which proposes an integrated user model for a specific goal within a specific context [1].

The Friend of a Friend (FOAF) ontology[6] is a top level ontology that models generic information about a user, including their name, social graph, interests and location. However, current FOAF profiling is based on the *static* representation of, in some cases, highly changing data, such as the temporal location of a user, or their current position in the world (à la *foursquare*[7]). Since many of these highly changing user properties can be observed through sensors, different ontologies for considering sensor data in user modelling have emerged. The Service-Oriented Context-Aware Middleware (SOCAM) ontology [11] is an upper ontology which introduces concepts like `Activity`, `Location`, `ComputationalEntity` and `Time` under the umbrella

[6] FOAF ontology: `http://xmlns.com/foaf/spec`

[7] `http://www.foursquare.com`

concept of ContextEntity. Although it models sensors using the Device concept, it does not provide a link between a sensor and its owner, nor a relation between the sensor's observations and user properties.

The General User Model Ontology (GUMO) is a top-level ontology introduced in 2005 [14]. GUMO is based on the User Mark-up Language (UserML) [13] and considers dimensions including personality, demographics, emotional and physiological state. The use of sensors in GUMO is considered particularly for users' physiological state; Heckman et al. [14] suggest the use of wearable bio-sensors to register users' body conditions such as pupil dilation and blood pressure. Although they consider the use of UbisWorld[8] for integrating users in ubiquitous environments, there is no clear definition of the way in which a sensor's relationship with a user's properties could be addressed.

The Ontonym ontologies[9] [25] are a collection of seven upper ontologies for pervasive computing. including the *Sensor*, *Device* and *Person* ontologies. They are designed to allow the definition of ownership between a Sensor and a Person through the Device class's owns and ownedBy properties. However, Ontonym requires the definition of a new ontology to map each sensor observation to user properties. For example, to add a relationship between a user's mobile device GPS's location observations and the user's location, the *Location* ontology is defined to declare the Locatable-Entity and LocatableFeature classes (and associated properties). Ontonym is, to the best of our knowledge the only user modelling ontology available online.

Work done in sensor data integration into ontology-based user modelling following a bottom-up approach includes the Mobile Ontology-based Reasoning and Feedback System (MORF) [2], which defines a set of domain-specific ontologies which include classes such as Patient, Doctor and HeartRateSensorData. Their model allows monitoring and transmitting a patient's data through a mobile device. However, restrictions due to domain-specific design prevent MORF and other such bottom-up ontologies from being extensible to generic user modelling.

Relevant components of standard ontologies are discussed in the requirements identified in section 4 and revisited in 5.4 where we assess the extent to which these are met.

4 Requirements

The scenario presented in section 2.3 highlights not only the relevance of the identification of sensors and their observations as meaningful web resources, but also the importance of addressing the generated data streams as users' feature properties. In this section, we identify requirements for associating sensor data to user modelling.

Identification and Addressability: To uniquely identify and dereference sensor resources. In our scenario, Alice should be able to identify Bob's sensors, as well as the potential relations among these sensors. For example, by exposing Bob's physical activity and sugar levels, through the definition of his pedometer, as well as his glucose sensor as web resources, health care services could react in a contingency situation, in which external entities such as nearby emergency medical services could respond according to Bob's physical location (see section 6.2).

[8] UbisWorld can be tested at: http://www.ubisworld.org

[9] Ontonym ontologies: http://ontonym.org

Sensor Ownership and Provenance: To establish the sources of information, including entities and processes involved in the generation of measurements from observed stimuli. Provenance in sensor data is crucial for assessing trust judgements on information. An Entity, in particular a Person, should be able to address a sensor as its own – Bob, for instance, should be able to associate sensors with himself. Given a sensor data stream, it should be possible to access the sensor publishing the given stream and identify the sensor's owner. In the scenario, Alice and the GP should be able to identify the streams they are consuming as Bob's.

Association of Sensor Data and Profile Information: To map explicitly, a user's property characterised by a stimulus with the sensor that observes this stimulus. In the scenario, Alice must be able to associate Bob's (continuously changing) location with, e.g., Bob's current_location property, observed by his GPS.

Privacy in Data Streams: To consider how identity information should be exposed and to whom: (1) The consumer of a data stream should be guaranteed that no other service has impersonated the sender; (2) The owner of a data stream should be able to establish authentication methods so only authorised consumers have access to it. E.g., besides Bob, Alice should be authorised to access Bob's health information, as well as the closest emergency doctor who treats Bob at the scene (the latter will have access to a filtered view).

Sensor Data Expiration: To enable a data stream to declare an estimation of the period of time in which its data should be considered valuable. In our scenario, Alice must be able to tell if the received information is still valid, e.g., Alice must know the latest (valid) position of Bob and the time beyond which it is no longer valid.

Interaction with Smart Entities: To allow the representation of collective stimuli in which different entities, including the user, are involved. With collective stimuli we refer to the aggregation of common detectable changes in observable properties. E.g., Bob's location-based proximity social graph is a property derived from the collective stimulus of being located in the vicinity of Bob, within a radius of 5km.

Integrate Physical and Virtual Presence Stimuli: To identify and incorporate virtual and physical stimuli as part of a user's presence. This integration would bridge the user's physical and online personae. In the scenario, the NutrApp would make use of Bob's online social network to obtain the references of those entities to be monitored for physical presence proximity.

5 The Sensing Presence Ontology

In this section we introduce concepts related to users' presence and present the Sensing Presence (PreSense) Ontology[10]. It defines key concepts and properties required to describe users' features in terms of virtual sensor observables. PreSense models users as entities whose presence is the aggregation of online and physical properties. It represents sensors' observations for deriving presence properties and particular features of interest, following the Stimulus-Sensor-Observation (SSO) ontology design pattern [18]. Fig. 2 illustrates the structure of the PreSense ontology, focusing on the relationships between its core components.

[10] PreSense ontology available at: http://purl.org/net/preSense/ns

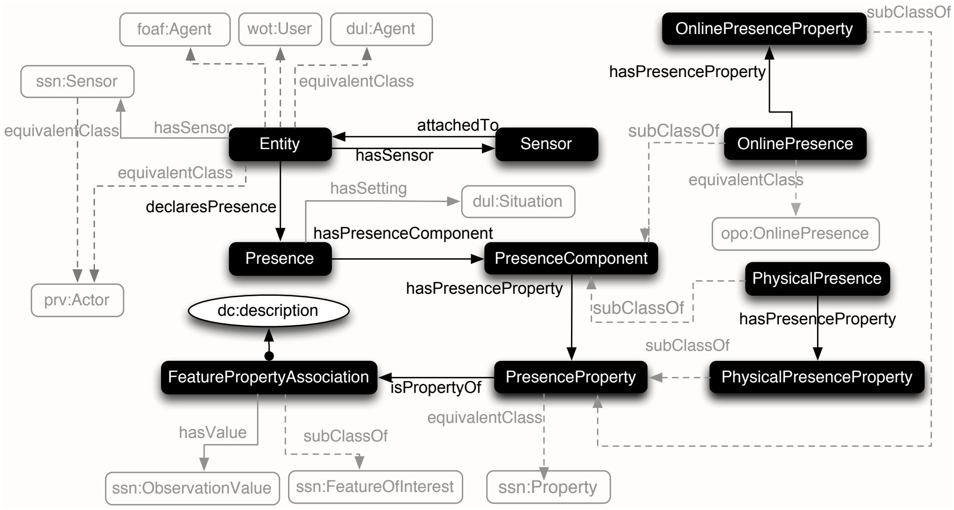

Fig. 2. Sensing Presence Ontology (`PreSense`) Overview

5.1 User Modelling Based on Personal Sensors

Based on the definition of virtual sensors (in section 2.2) and the SSO design pattern [18], we introduce the concept of "*personal sensors*" to refer to both physical sensor devices and compositions of computations or procedures that measure a user's properties. The information embedded in the data produced by personal sensors includes the users' *online* and *physical presence contexts*. By *online presence context*, we refer to the information provided by the aggregation of personal data streams (e.g. microblog posts, emails, text messages) generated by a user within a window of time. We consider the *physical presence context* as the abstraction of physical features, measured by sensor devices, regarding a user's state of existence or being present in a place or a thing (e.g. the user's location, body temperature). Both online and physical presence interweave dynamically with a user's surrounding environmental context, which can include other entities like people, places and things (e.g. members of the user's social graph who are close by, or local points of interest – POIs).

5.2 Imported Ontologies

Specifications on how to exchange sensor data and their observations have been defined by the Open Geospatial Consortium (OGC). In particular the OGC's Sensor Web Enablement[11] (SWE) suite is a broad standardisation initiative which comprises models such as the Sensor Model Language[12] (SensorML) and the Observation & Measurement[13] (O&M) standards, and services such as the Sensor Observation Service (SOS)

[11] `http://www.opengeospatial.org/projects/groups/sensorweb`
[12] `http://www.opengeospatial.org/standards/sensorml`
[13] `http://www.opengeospatial.org/standards/om`

[18]. However, sensor data sharing and discovery expose different challenges involving semantic heterogeneity and integration. The Semantic Sensor Web (SSW) [24] approaches these challenges by providing an ontological platform that defines a machine-readable specification of the conceptualisations that underlie this sensor data.

There are over twelve sensor ontologies [5] for declaring a specification of sensing devices; some include sensors' domain definitions and their relation to observations and measurements. The need for a domain independent and end-to-end model for sensing applications led to the creation of the W3C's Semantic Sensor Network Incubator Group[14] (SSN-XG), who developed the Sensor and Sensor Network (SSN) ontology[15] [6,22]. Taking into account available standards such as the OGC's SWE, the `SSN` ontology merges sensor-, observation- and system-focused views. The ontology describes sensors following the SSO ontology design pattern [18] and considers spatial provenance properties through the `SSN`'s `Deployment` module.

Following ongoing research and standardisation efforts, we use the `SSN` ontology to represent sensors in `PreSense`. Further, we use the Provenance Vocabulary[16] (PRV) [12] to extend provenance-related metadata regarding both sensors and their owners through `prv:Actor`. For modelling an `Entity` asserting the ownership of a sensor, we use `foaf:Agent`. According to the `FOAF` specification, a `foaf:Agent` can refer to a person, a group, software or a physical artifact. The Web of Trust[17] (WOT) ontology is used to ensure that the ownership of a sensor cannot be falsified by a third party, thus providing a solid base for valid sensor attachment. `PreSense` models a user to be equivalent to a `wot:User`. This equivalence allows a user to assert a digital signature to a web resource, which ensures that: (1) The provenance of the resource cannot be falsified easily; (2) The resource cannot be modified without revoking the provenance of the information.

From the Online Presence Ontology[18] (OPO), we reuse `opo:OnlinePresence` to model users' online presence properties. Finally, from the Dolce Ultralight Ontology (DUL) [19] we reuse `dul:Agent` to align existing properties of `SSN` with a `preSense:Entity` (abbreviated prefix `ps:` used hereafter), and `dul:Situation`, in defining the contextual setting of an entity's `ps:Presence`.

5.3 Core Components

Table 1 summarises the requirements fulfilled by each of the core components of the `PreSense` ontology, which we discuss next:

Entity An entity is modelled to be equivalent to `foaf:Agent`, `wot:User`, `dul:Agent` and `prv:Actor`. The function of the `Entity` class is twofold: (1) to describe the identity of an individual (not only persons but entities in general) to whom the sensor data should be attached; and (2) to avoid provenance falsification

[14] SSN Incubator Group: `http://www.w3.org/2005/Incubator/ssn/wiki`
[15] SSN Ontology: `http://purl.oclc.org/NET/ssnx/ssn`
[16] Provenance Vocabulary: `http://purl.org/net/provenance`
[17] WOT Ontology: `http://xmlns.com/wot/0.1`
[18] Online Presence Ontology: `http://online-presence.net/opo/spec`
[19] Dolce Ultralight Ontology : `http://www.loa-cnr.it/ontologies/DUL.owl`

Table 1. Match of core PreSense ontology components to requirements

	Ident. & Address-ability of Sensors	Sensor's Ownership & Prove-nance	Sensor & User Profile Assoc.	Privacy	Data Expiration	Interaction with Smart Objects	Integration of Phys. & Virt. Pres. Stimuli
Entity	•	•	–	◦	–	–	–
Sensor	–	–	•	–	•	•	–
Presence	–	–	–	–	–	•	•
PhysicalPresence	–	–	–	–	–	•	•
OnlinePresence	–	–	–	–	–	–	•
FeaturePropAssoc.	–	–	•	–	–	–	–

Legend: • Yes. ◦ Limited. – No.

through the use of digital signatures in wot:User. The Entity class considers the property hasSensor for attaching a sensor to an entity (its inverse property is attachedTo). Entity is skos:closeMatch with ssn:Platform, which is considered to be an Entity to which a System of sensors is attached. However, SSN considers a Platform to be a dul:PhysicalObject which is disjoint with dul:SocialObject.

Sensor A sensor is defined by the ssn:Sensor class and refers to a physical object that detects, observes and measures a stimulus. The ps:attachedTo property is used to assert that a ps:Entity owns this sensor (its inverse property is ps:hasSensor). In order to extend provenance metadata of a sensor and its observations, we model the ssn:Sensor to be equivalent to a prv:Actor.

Presence A Presence refers to the state or fact of existing or being manifest in a place or a thing. We consider that a Presence is an aggregation of an Entity's online and physical manifestations, that occur within a situation or setting. Following DUL, a situation is defined as a "*relational context*" created by an observer on the basis of a description frame.

Physical Presence This is the abstraction of the aggregation of physical properties featuring a quality of an entity. These properties are derived by sensors observing physical stimuli. The ps:PhysicalPresence class manifests an entity to be in a state of existing or being present in a place or a thing. These physical presence properties can be broken down into different modules regarding different dimensions in which users' properties can be linked to sensor data.

Online Presence This is equivalent to opo:OnlinePresence; it refers to the abstraction of the aggregation of online properties featuring a quality of an Entity, e.g., a user. These properties are derived by virtual sensors observing stimuli involving this Entity, e.g., the detection of a user's change of status on a social network site through the ps:OnlineStatusStream.

Feature Property Association Following the SSO ontology design pattern we introduce this class to bridge a sensor's observed stimulus and the feature that this stimulus characterises in the user model. It is a subclass of ssn:FeatureOfInterest; which being an abstraction of real world phenomena, proxies a stimulus through a quality that can be observed by (an ssn:Property of) a sensor, and the PreSense property describing this quality (i.e., ps:PresenceProperty). The ps:FeaturePropertyAssociation class establishes a relation with the ps:Presence through the property ps:hasPresenceProperty, and by declaring ps:PresenceProperty to be owl:sameAs ssn:Property.

5.4 Fulfilment of the Requirements

The PreSense ontology addresses all of the requirements identified in section 4. Table 2 summarises the differences between the PreSense Ontology and the existing upper ontologies introduced in section 3.

Table 2. The PreSense Ontology, compared to existing, standard models

	Ident. & Address-ability of Sensors	Sensor's Ownership	Sensor's Prove-nance	Sensor & User Profile Assoc.	Privacy	Data Expiration	Interaction with Smart Objects	Integration of Phys. & Virt. Pres. Stimuli
FOAF	–	–	–	–	–	○	–	○
SOCAM	○	–	○	–	–	○	●	○
GUMO	–	●	–	–	–	○	○	○
Ontonym	–	●	●	–	–	●	–	–
PreSense	●	●	●	●	○	●	●	●

Legend: ● Yes. ○ Limited. – No.

PreSense uses the SSN:Sensor ontology to model sensors and sensor data. Entity acts as the bridge through which sensor data and profile information can be associated. By reusing the FOAF, WOT and PRV ontologies, entities and sensor ownership can be uniquely identified. The use of WOT partially covers privacy issues. However questions still remain about the correct structure for introducing privacy settings within data streams; we aim to tackle this in future work. Sensor data expiration can be handled using ssn:observationSamplingTime. PreSense allows the representation of physical and online presence and their corresponding properties by enabling a bridge between a user's properties and the sensors observing these properties.

6 Applying PreSense

This section revisits the scenarios presented in section 2.3 and provides an overview on how to represent different information with the PreSense core ontology.

6.1 Extending PreSense Core Ontology with Modules

PreSense modules are extensions to the PreSense core vocabulary that provide additional information regarding a specific type of property. Currently PreSense has two modules, the *spatial properties* module and the *health properties* module. The spatial property module includes `Location`, which is a spatial quality of an entity; this property is linked to a sensor by the `ps:FeaturePropertyAssociation` whose value is the observation of, in this case, a GPS sensor. The health properties module considers the `PhysiologicalState` class and its subclasses (Fig. 3).

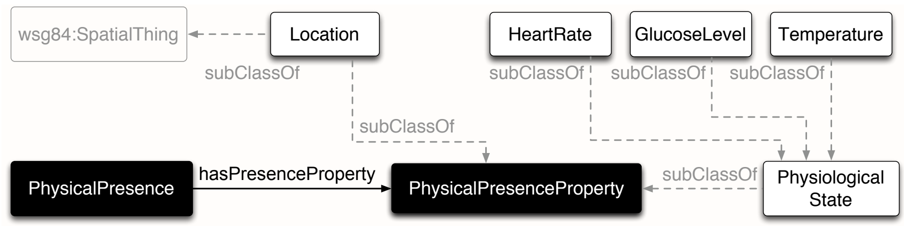

Fig. 3. `PreSense` modules for handling features related to `Location` and `PhysiologicalState`.

6.2 Scenario with PreSense

In this scenario Bob's levels of glucose can be monitored as part of his profile. This could be modelled with the `PreSense` ontology as:

```
 @prefix ps: <http://purl.org/net/preSense/ns\#>  .
 @prefix physioState: <http://purl.org/net/preSense/physioState/ns\#>  .
@prefix prvTypes: <http://purl.org/net/provenance/types#> .
 @prefix prv: <http://purl.org/net/provenance/ns>  .
 @prefix ssn: <http://purl.oclc.org/NET/ssnx/ssn\#>  .
 <http://my.identity.org/Bob> a ps:Entity, a foaf:Person;
 ps:hasSensor <http://my.identity.org/Bob/sensors/glSen1/>.
 ps:declaresPresence _:p1.

 _:p1 a ps:Presence;
   ps:hasPresenceComponent _:phyPr.

 _:phyPr a ps:PhysicalPresence;
   ps:hasPresenceProperty _:prop1.

 _:prop1 a physioState:GlucoseLevel;
   ps:hasPresenceProperty _:glucoseLevel.
   ps:isPropertyOf _:bloodGlucose .

 <http://my.identity.org/Bob/sensors/glSen1/>
   a ssn:Sensor, prv:Actor, prvTypes:Sensor;
   prv:operatedBy <http://my.identity.org/Bob> .
   prv:observedBy <http://my.identity.org/Bob/sos/observations/glSen1/>.
 <http://my.identity.org/Bob/sos/observations/glSen1/> a ssn:Observation;
   ssn:observedProperty _:glucoseLevel.
 _:glucoseLevel   a ssn:Property, ps:PresenceProperty;
   ssn:isPropertyOf _:bloodGlucose.
 _:bloodGlucose   a ps:FeaturePropertyAssociation;
```

In this example, Bob registers his glucose level measuring sensor (`glSen1`) and his physical presence (`phyPr`). His physical presence considers in this example the health properties module; in particular the glucose level property (glucoseLevel). This property corresponds to the property observed by his glSen1 sensor. This sensor observes changes in his blood sugar levels, (bloodGlucose), which is the feature of interest. This association enables Alice to monitor Bob's sugar levels. Following the URI scheme for linked sensor data proposed by Janowicz et al. [17], Alice could refer to, e.g., http://my.identity.org/Bob/sos/observations/glSen1/mgPerdL, which is a reference to all observations gathered by glSen1 corresponding to the feature of interest bloodGlucose for the observed property, milligrams per decilitre, mgPerdL. In a similar way the PreSense ontology could be applied for registering Bob's heart rate micro-sensor.

The scenario also considers the attachment of virtual sensors to the user's profile. Bob could allow other systems to consume his online status stream (e.g., tweet streams) as:

```
<http://my.identity.org/Bob> a ps:Entity, a foaf:Person;
ps:hasSensor <http://my.identity.org/Bob/sensors/stSen1/>.
ps:declaresPresence _:p1.

_:p1 a ps:Presence;
  ps:hasPresenceComponent _:onlPr.

_:onlPr a ps:OnlinePresence;
  ps:hasPresenceProperty _:prop2.

_:prop2 a ps:OnlineStatusStream;
  ps:hasPresenceProperty _:personalStatusStream.
  ps:isPropertyOf _:twitterStatusStream .


<http://my.identity.org/Bob/sensors/stSen1/>
  a ssn:Sensor, prv:Actor, prvTypes:Sensor;
  prv:operatedBy <http://my.identity.org/Bob> .
  prv:observedBy <http://my.identity.org/Bob/sos/observations/stSen1/>.
<http://my.identity.org/Bob/sos/observations/stSen1/> a ssn:Observation;
  ssn:observedProperty :personalStatusStream.
_:personalStatusStream   a ssn:Property, ps:PresenceProperty;
  ssn:isPropertyOf _:twitterStatusStream.
_:twitterStatusStream   a ps:FeaturePropertyAssociation
```

In this case, Bob declares his personal status stream as a property of his online presence onlPr. This property is a proxy for generated contingency tweets on behalf of Bob, and is observed by the virtual sensor stSen1. In this case all observations regarding generated tweets could be obtained through http://my.identity.org/Bob/-sos/observations/stSen1/status. Data derived from his health monitoring devices could trigger an alert when Bob is facing a health contingency situation. This alert could be proxied through Bob's stSen1 sensor; which could alert, e.g., a particular list of Bob's followers in his physical environment about his need for medical attention. They in turn could, on validating the information and its provenance, notify health services about the impending emergency.

7 Conclusions

The PreSense ontology is designed to extend people's digital identities through the information obtained by their attached personal sensors. It provides a first step toward the integration of user modelling and "smart environments". `PreSense` distinguishes between the notions of physical presence, e.g., location data obtained from digital sensors, and virtual presence, provided, for instance, by the aggregation of personal data streams, but affords equal status to both. Moreover, `PreSense` allows the assignment of meaning to sensors' observations in terms of user modelling features.

Future work includes the development of `PreSense` modules addressing interaction with smart entities and environments, by mapping a user's location to that of other nearby entities (*NearByPOI* and *NearByFriends* modules). We are also testing the application of the `PreSense` ontology in real world scenarios, starting with the exploration of new environments and ongoing events. We plan to carry out an evaluation of `PreSense` during the Tramlines Festival[20] in Sheffield in July 2011. Bearing in mind privacy restrictions, only information about participants' interests in music and festivals, and preferences when exploring a new location will be broadcast. Our architecture relies on SparqlPush[21], which handles real-time notifications by associating feeds with SPARQL/Update[22] triggers. Collective information on events and POIs, gathered from Twitter and public Facebook feeds, will be filtered based on users' profiles and their current geo-location (`ps:PhysicalPresence`), obtained from GPS on their mobile devices. Where public, users' online status information (`ps:OnlinePresence`) will be used as an additional filter, e.g., to suggest festival events and `NearbyPOIs` that other users with similar interests have visited, and notify them about `NearByFriends`.

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[20] Tramlines Festival 2011: `http://www.tramlines.org.uk`
[21] SparqlPush: `http://code.google.com/p/sparqlpush`
[22] SPARQL Update Language: `http://www.w3.org/Submission/SPARQL-Update`

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