Social devices: autonomous artifacts that communicate on the Internet

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Abstract. The Internet has boosted people collaboration, enabling new forms of exchanging knowledge and engaging in social activities. The Web 2.0 paradigm (also called the Social Web) has greatly contributed to this achievement. We believe that the next wave of smart devices and digital objects will leverage the pervasiveness of Internet connectivity in order to form ecosystems and societies of artifacts that implement Internet-based social behaviors and interact with existing Internet-based social networks. In this paper, we introduce the concept of *social device* and describe our experiences creating different kinds of augmented objects that use the Internet in order to promote socialization, look smarter and better serve users. We finally identify several challenges in the research of devices that behave in social ways.

1 Introduction

People are not isolated at their workplace or in public spaces: they meet, talk, exchange ideas and collaborate. In our modern world where no single person is likely to know everything about a particular domain, sharing information and cooperating is of foremost importance for the advance of the society.

In fact, complex tasks often require the combined contribution of different kinds of specialized knowledge and are also often more easily achieved as a collaborative activity. Nowadays, the concept of collaboration is itself undergoing a transformation driven by the new networked technologies. For example:

– Open Source communities have developed some of the most successful computer software applications in the last decade including GNU/Linux, Firefox, OpenOffice, Apache, Eclipse, and, more recently, the Java programming language that has also joined this trend.
– Collaborative content sites, created by the contributions of thousands of users, have been able to become the most important repositories of information in a surprisingly short time. The most popular examples are Wikipedia and YouTube.
– In P2P file exchange networks file sharing is promoted following the scheme "the more you share, the further ahead you are placed in download queues".

The Web has transformed from a place with many readers and few publishers, into a space where everyone can have a voice via tools such as blogs (weblogs), or a community of users can collaboratively create a body of knowledge about some concrete topic via wikis.

This evolution of the Web has been dubbed Web 2.0 or Social Web, and it promises to boost human collaboration capabilities on a worldwide scale, enabling individuals and organizations to face challenges that could not have been faced in isolation. In the very same way, there is clear evidence that digital and electronic devices should not be isolated in the places where they are deployed or spontaneously meet.

We are witnessing an unprecedented increasing number of digital objects that are populating and almost invading more and more environments in an imperceptible way. Most of times, they carry out simple but efficient tasks that help people in their everyday activities, simplifying their lives. However, when it comes to complex tasks involving a higher-level of intelligence and cooperation in unexpected situations or scenarios, they invariably fail, because *they have not been designed for collaboration*.

Just as Web 2.0 technologies have boosted human social capabilities on the Web, devices can also benefit from similar schemes, using the Internet in order to communicate, collaborate, use global knowledge to solve local problems and perform in exciting new ways.

In this paper, we present some concepts about devices powered with Internet-friendly social capabilities, and describe our experiences. In section 2, we refer to previous work on integrating Internet, especially Web-based technologies, into everyday objects. Section 3 is devoted to the analysis of desired features of social devices that communicate through the Internet. Section 4 includes a description of several prototypes of devices we have implemented that use Internet to communicate with other entities. Finally, in section 5 we identify different challenges associated with the design of everyday objects that behave in social ways, which must be addressed by the research community.

2 Related work

Internet and, particularly, Web technologies have been used in the past to create exciting Ubiquitous Computing scenarios where objects are gifted with augmented capabilities. Cooltown [9] [10] [1] was a pioneer project applying Web technologies to support users of wireless, handheld devices interacting with their environment, anywhere they may be. WSAMI [5] enables the creation of Ambient Intelligence scenarios controlled by Web-based invocation mechanisms, Web Services.

Remarkably, the last few years have witnessed an increasing interest in the application of a particular type of Web technologies, Semantic Web technologies, to create connected societies of smarter artifacts. Semantic Web technologies (RDF [23] and OWL [22]) have been used in several projects in order to provide more intelligence in environments. In the Semantic Web, URIs are used for representing concepts, while HTTP [3] provides a natural means for retrieving RDF-based descriptions. Task Computing [13] [17] aimed at creating Semantic Web Services-based systems in which users could perform automatic composition of services, based on semantic service descriptions.

Other architectures such as CoBrA [2] provided both an architecture and an ontology (SOUPA) to create environments populated by smart devices that could communicate through the Internet using Semantic Web technologies. However, CoBrA requires a central server to be deployed where all the intelligence resides, acting the devices as simple slave entities out of the context-awareness process.

SoaM (Smart Objects Awareness and Adaptation Model) [18] [21] eliminated the need for a central component, and introduced the concept of collaborating *semantic devices*. The results demonstrated that spontaneous emergent intelligence could be achieved by the collaboration of individual objects that may access the Internet for retrieving data and ontologies.

Currently, one of the most popular approaches to implement Internet of Things experiences is the use of "touch computing" along with object tagging [16] [12] in order to obtain further information about a concrete object from the Internet. Mobile devices are generally used in these cases as service "activators".

However, the vision of a coherent and heterogeneous society of Internet-connected objects ("*from anytime, any place connectivity for anyone, we will now have connectivity for anything*" [4]) is in its first steps of realization. We think that current research must explore the possibility of embedding *social capabilities in objects and devices* in order to realize the "Internet of Things" vision as a replica to the current "Internet of People" reality. A lot of people use the Internet to find others' solutions to a particular personal issue; that is, they use global information for a local purpose.

In our vision, "social devices" should work very much in the same way. When facing a local problem, devices can "talk" with other artifacts that can provide their experience about that situation, or additional information that may help to come up with a solution. In the next section, we will describe the features that this kind of social devices must embody.

3 Features of social devices

Lassila and Adler [11] introduced the concept of *semantic gadget* to describe devices capable of performing "*discovery and utilization of services without human guidance or intervention, thus enabling formation of device coalitions*". Vazquez et al. [18] [20] introduced the concept of semantic device as a system "*able to spontaneously discover, exchange and share context information with other fellow semantic devices as well as augment this context information via reasoning in order to better understand the situation and perform the appropriate reactive response*".

The concept of *social device* emphasizes even more the benefits of the communication with other devices in order to determine the appropriate behavior. Internet is the enabling technology in this case, since the knowledge provided by local devices can be complemented with information obtained from the Internet (provided in turn by other devices, services, or humans). Further below, we will illustrate this situation with the example of a prototyped umbrella which is able to obtain current weather conditions through communication with surrounding rain sensors, but it is also able to download the weather forecast from the Internet (`weather.com`) in order to provide better advice to the user.

We have identified several characteristics that may help to define the concept of social device:

- Social devices are natively designed for collaboration
- Social devices integrate local and global information (obtained from the Internet) in order to apply community knowledge to particular problems
- Social devices are able to interpret all the exchanged information at a semantic level, whatever the vocabulary used

3.1 Designed for collaboration

Social devices are inherently talkative: they are natively collaborative in the sense that they share all the information they can.

As already mentioned, the Web has transitioned from a basically “one publisher – many readers” model to a more collaborative “many publishers – many readers” model, in an approach that was called Web 2.0 [15]. The major representatives of this culture are weblogs, social bookmarking, wikis and RSS feeds.

We consider that this model can be also applied to devices, featuring a collaborative nature, sharing information, and creating a community of intelligent objects in the environment in order to better serve their users.

Higher and more useful knowledge can be obtained from the generous contributions of individual entities, rather than from selfishly not sharing information (of course, taking into account existing privacy concerns).

On the other hand, social devices can also interact with existing social networks (e.g., Facebook, YouTube, Flickr, Digg) in order to monitor some information on behalf of their user/owner. For example, a Flickr-enabled digital photo frame can periodically check whether new photos from the user’s buddies have been published, download them and start a slideshow.

In this case, objects use existing social network infrastructure as a medium for retrieving user-related content. These social objects may also send data back to the social network (e.g., the user may vote for a photo in order to increase its popularity), thus becoming active participants in the community.

These scenarios illustrate how for some simple, well-defined activities users may interact with the social network via real objects instead of using a computer and a browser. These objects promote users’ socialization in a transparent, unobtrusive way.

3.2 Integration of local and global information

Users do not have the ability to connect their minds to the Internet, but devices can exhibit this feature. By managing more information they look more intelligent, as in the case of the weather-aware umbrella.

There are ubiquitous examples of this feature: a car may recommend the best route based on data provided by other surrounding cars and traffic information downloaded from the Internet; an eBay-aware ornament at the home entrance may project a green light beam if our bid was successful or a red one if not, as the user arrives home.

We have developed several prototypes of objects (described below in section 4) that simultaneously obtain context information provided by other local objects in the environment as well as remote services on the Internet, integrating all this knowledge to realize a higher level of context-awareness. In our prototypes local information was typically provided by wireless sensor network nodes, while global information was provided by public XML-based Web Services on the Internet. In both cases, we designed adapters that semantically annotated the data using RDF, and shared this information with all the entities in the environment, creating a distributed knowledge space, so existing objects could analyze the semantic context information and react in the desired ways [18].

3.3 Interpretation of information at a semantic level

The vision of a myriad of social devices "talking" both at local and global level exposes the problem of the number of formats and vocabularies for exchanged information and messages. In our experiments [18] we used Semantic Web technologies, RDF and OWL, in order to support multiple vocabularies and dynamically learn relationships among concepts using ontologies.

We humans interpret the information on the Web at a semantic level, being able to understand, process and use it. Social devices should be able to perform in the same way: this is the main reason to apply semantic technologies.

Of course, this level of intelligence requires additional computation capabilities on devices (e.g., able to run a semantic reasoner), but we believe that semantic interpretation is a feature inherent to social communication, without imposing limitations in expressiveness or vocabularies.

The use of microformats [7] as an alternative provides the additional advantage that it is easier for humans to create microformats-enriched content than RDF-annotated content. This approach enables devices to interpret, at a basic level, user-generated content in blogs, wikis, and so forth, without demanding much effort from the contributors, thus bridging the communication gap between users and devices on the Internet.

4 Experiences prototyping social devices

During the last years we have been researching the implications of Internet connected objects and their interaction with users. We have also developed several prototypes in order to evaluate their potential. The following subsections describe some of these prototypes.

4.1 Flexeo's SensorMap: a wireless sensor network –based mash-up

The goal of the project Flexeo was designing a system for remotely monitoring wireless sensor networks through the Internet, and integrating all the data into business processes in order to execute data-mining operations and determine correlations among data. Scenarios related to "health at home" and remote monitoring of industrial facilities were designed in order to test the resulting system.

As an additional outcome, a mash-up of sensor collected data and Google Maps was developed, called SensorMap. This subsystem illustrated the potential applications of publishing up-to-date sensor data on the Internet in order to dynamically integrate different sources of information for providing higher level services.

Figure 1 shows a sensorized chair with two pressure sensors (at the seat and at the back) connected to a wireless sensor network node in order to provide information about its use to local and remote objects. Figure 2 contains a screenshot of the SensorMap application showing the state of the chair (if someone is sat on and/or leaned backwards).

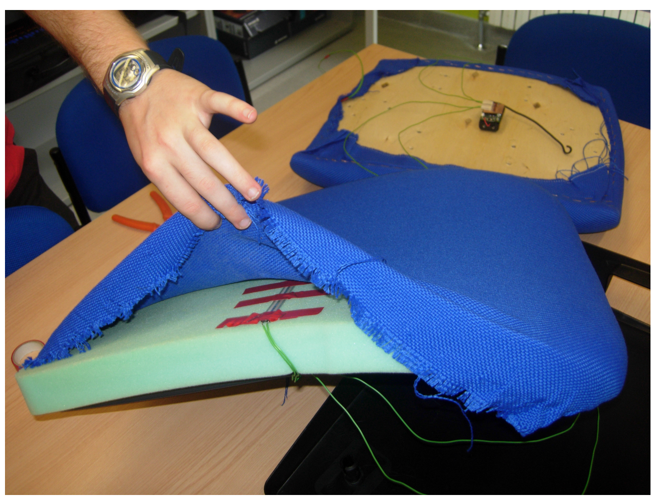

Fig. 1. Preparing the chair with pressure sensors and a WSN node.

Flexeo's architecture was divided in to three different layers: the sensor layer, the concentrator layer and the business logic level.

The sensor layer was based on a wireless sensor network formed by Crossbow Mica2 nodes embedded into everyday objects such as a chair, a container, a wear-

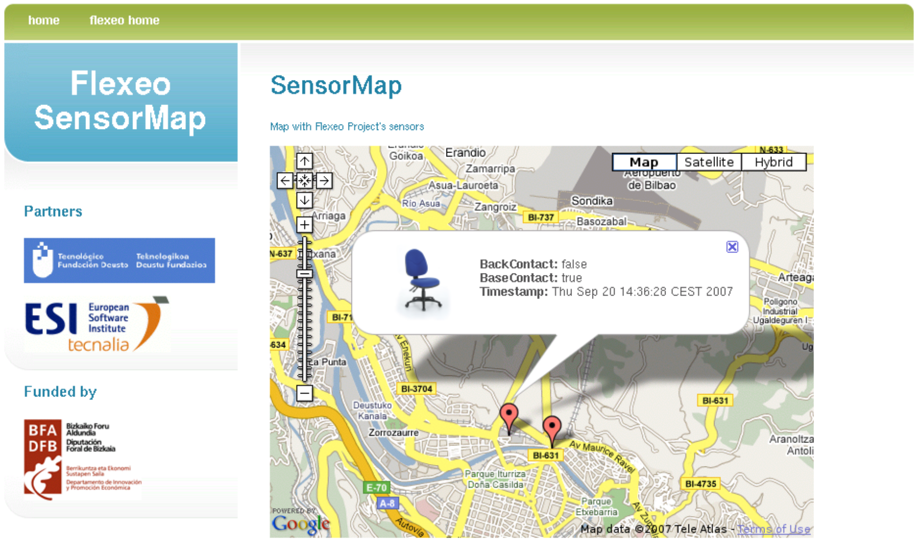

Fig. 2. Flexeo's SensorMap showing the state of a chair.

able band and a wristwatch. The main goal was transforming different existing objects into wireless nodes, able to provide data about users' interactions.

The concentrator layer was implemented using an embedded computer, a Gumstix connex 400xm, connected both to the wireless sensor network and to the Internet via GPRS and/or Wi-Fi. The concentrator featured a middleware layer implemented using Java in the form of OSGi components, that was in charge of polling the sensor network, interpreting the data, evaluating rules in order to detect alarms, and grouping the data for sending them to the business logic servers that were on the Internet. In Flexeo, the concentrator was the architectural element in charge of connecting the sensor nodes, and thus, the real objects they were embedded in, to the Internet, acting as a communication gateway.

4.2 RealWidgets: from the desktop to the real world

Desktop-based operating systems are increasingly using some mini-applications called *widgets* or *gadgets* in order to provide small services or show concrete up-to-date information to users. Yahoo! Widgets, Apple Mac OS X Dashboard, Google Gadgets and Microsoft Windows Vista Gadgets are the most popular flavors of this form of interaction. Often, these widgets connect to online services in the Internet in order to provide weather or traffic information, most-popular YouTube videos, latests news, and so forth.

With RealWidgets we wanted to embody the functional capabilities of these digital entities into real world tiny wireless displays, in order to have small "windows" deployed everywhere opened to the information from the Internet.

The RealWidget is formed by an OLED display, with high resolution and contrast while small energy consumption, integrated with a Crossbow Mote2 wireless sensor network node. A computer acted as a gateway between the Internet and the wireless sensor network, running a RealWidget Management Application that connected to the required sites on the Web, downloaded the information, analyzed it and finally sent the content to the appropriate widget as configured by the user. Figure 3 illustrates a RealWidget showing information about the liquid level in a remote chemical container that was monitored by a wireless sensor network over the Internet.

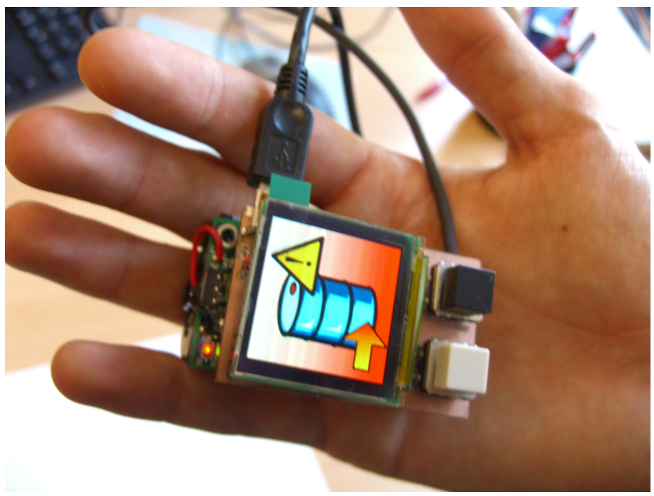

Fig. 3. RealWidget alerting about the liquid level in a tank.

Two buttons were provided for interacting with the RealWidget, basically for managing the energy by postponing the information for a later time, or immediately discarding it.

One of the most popular widgets in computer desktops are those related to weather information, so one of the earliest examples of the RealWidget prototype involved obtaining the data from a weather information site on the Internet. We chose `weather.com` due to the availability of an open API that provided the ability to download an XML document with the weather forecast for any location in the world.

The RealWidget Management Application could host different adapters that acted as gateways between the Internet service and the physical RealWidgets. In the previous example, we created an adapter that was able to connect to the `weather.com` website, retrieve the XML document with the weather forecast of the configured location, and transformed it into a notification message that was sent to the RealWidget. If any change in the weather information forecast occurred, subsequent notification messages would be sent to the RealWidget. The Crossbow Mica2 wireless node on the RealWidget received the message, processed it, and displayed an icon on the OLED display representing the weather conditions (sunny, cloudy, raining, and so forth).

4.3 SmartPlants: autonomous objects that interact with their environment

SmartPlant was one of the evaluation prototypes we designed for the SoaM (Smart Objects Awareness and Adaptation Model) [21] platform: a completely decentralized architecture for designing semantic devices that collaborate by sharing information about the environment, and spontaneously react to changes in the context. The two pillars of SoaM are a semantic discovery protocol called mRDP (Multicast Resource Discovery Protocol) [19], and proactive semantic information exchange among entities. The result is an architecture in which devices create dynamic communication flows, and perform semantic reasoning over context information contributed by all the entities in the environment in order to determine the most appropriate behavior.

One of the scenarios we envisioned at the beginning of the research was to create an artifact that could be attached to real objects, augmenting their perceptions and providing them with intelligent capabilities. An additional challenge was to attach this kind of artifact to living entities, such as plants, in a way that could result in intelligent behavior carried out by the entities from the user's point of view.

An important part of this smart behavior was realized by obtaining additional knowledge about the environment from the Internet. Creating this kind of "smart plants" raised several new important implications such as:

- They could become first-class citizens in the environment, rather than passive elements. They could influence temperature, humidity or lighting settings.
- They could be perceived as autonomic systems [6] in a twofold view: as normal living beings they try to survive and adapt to environmental conditions; but also, as augmented intelligent entities they can interact and communicate with surrounding objects to create a more suitable and healthy environment.

Figure 4 depicts the smart plant prototype. The plant communicated at a semantic level with a wireless sensor network that provided temperature and light measures about different nearby locations, asking the user to me moved to the most suitable place using a synthesized voice. The plant was also able to download ontologies from the Internet in order to interpret particular expressions and predicates provided by surrounding sensors.

For all the semantic devices in SoaM, including the SmartPlant, we designed a computing platform consisting on a Gumstix connex 400xm with Wi-Fi com-

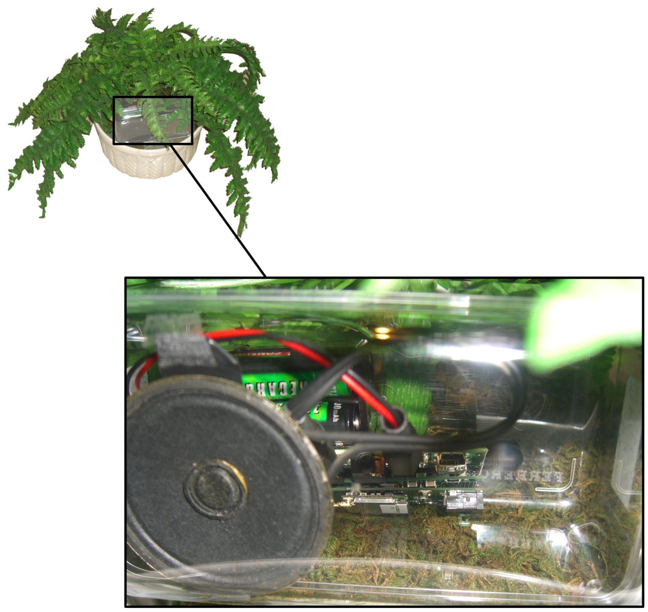

Fig. 4. The SmartPlant prototype.

munication capabilities, and a semantic middleware layer. The location a concrete ontology had to be downloaded from was stored in a central server on the Internet that acted as ontology index for the deployed objects.

In order to process semantic information and ontologies, we implemented a minimal semantic engine in the Gumstix called MiniOWL, able to interpret the most popular ontological relationships such as `rdfs:subClassOf`, `owl:sameAs`, `owl:TransitiveProperty`, `owl:SymmetricProperty` and `owl:inverseOf` [18]. Festival Lite was used as text-to-speech engine in the embedded computer.

The information captured by the wireless sensor network nodes was semantized by a software component running on a computer connected to the sensor network. We designed specific ontologies using OWL for this scenario in order to represent knowledge about lighting conditions, temperature, and location.

4.4 Aware-Umbrella: a reactive device integrating local and global communication

The Aware-Umbrella was also a semantic device designed for the evaluation of the SoaM architecture. As already mentioned, the ability to seamless integrate local and global information sources in order to augment local intelligence and knowledge is of foremost importance for social devices. The most probable, but not unique, source for this information is the Internet, and particularly, available dynamic web services.

Our goal in this scenario was to design some kind of social object that could be aware of both environment-provided and Internet-provided information in order to take decisions and look more intelligent from users' perspective.

Our choice was to create a smart umbrella that could obtain current weather information from surrounding sensors, as well as the weather forecast for the next hours from the Internet. The smart umbrella reacted when the user was leaving home without taking it by issuing a synthesized voice alert (see Figure 5).

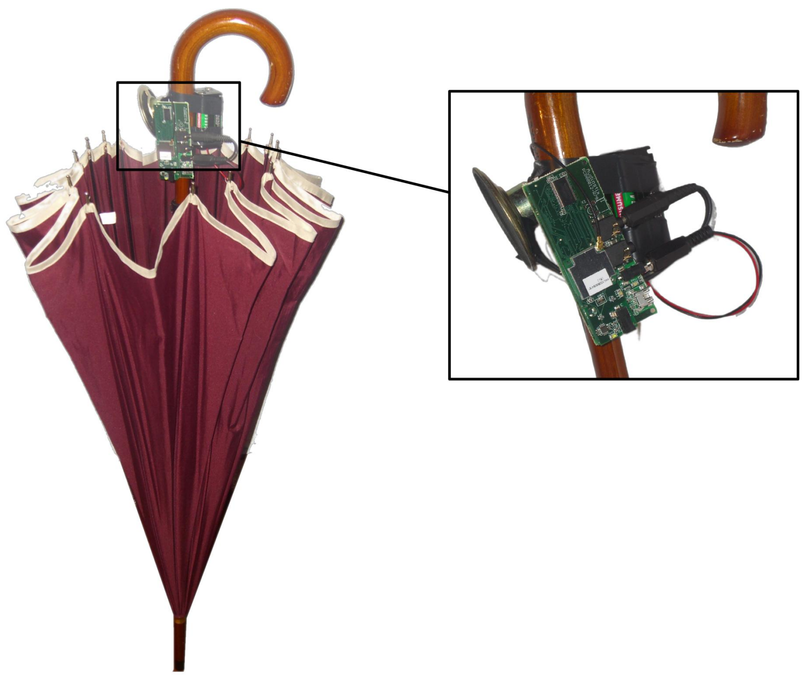

Fig. 5. The Aware-Umbrella prototype.

The umbrella obtained context information from the Internet through a "virtual software sensor", a small piece of code that connected to the Internet to get weather information about the town (provided by `weather.com`) and semantized these data using a weather ontology we designed specifically for this case. The umbrella finally checked the state of the door in case the user was leaving when raining in order to decide whether to issue the voice alert.

In this scenario we used the same computing platform designed for the semantic devices in the SoaM project: a Gumstix connex 400xm with a Wi-Fi interface, a semantic middleware layer, and the Festival Lite TTS engine. The state of the door was provided by a proximity sensor (based on a magnetometer) on a Crossbow Mica2 at the door. As in the previous scenario, a computer acted as a gateway between the sensor network and the Wi-Fi network, semantizing the information provided by the node at the door.

5 Challenges for Web 2.0-enabled things

Web 2.0 is a synonym for collaboration, a natural habitat for the prosumer model (consumer + producer). Since web technologies have been the most popular infrastructure for designing objects that communicate on the Internet, are Web 2.0-enabled objects the next evolution of this paradigm? What are the interfaces and synergies between users participating in social networks and the Internet of Things?

Based on the experiences we have mentioned in the previous section, we have identified three main challenges on the integration of Web 2.0 collaborative models and Internet-enabled objects:

- Creation of social networks formed by collaborative devices
- Objects as consumers and producers of content in existing human-oriented social networks
- Objects as interfaces with Web 2.0-based services

Figure 6 depicts in a graphical way the relationships among these three challenges: devices collaborating in environment-specific social networks, information flows between devices and social websites, and objects as interfaces for people to interact with human-oriented social networks. In the next subsections, some discussion about these challenges is provided.

5.1 Creation of social networks formed by collaborative devices

There are pervasive examples of Web 2.0 collaboration models that have boosted people participation: blogs, wikis, social tagging, social voting, content syndication, and so on. Are these models also suitable for boosting device collaboration on the Internet?

Devices can embrace Web 2.0-based communication models in order to implement a more human-like level of socialization. For people is relatively easy to understand the meaning of a blog entry, a photograph, or tags related to a website, since semantic interpretation is inherently human. However, when it comes to applying these social models to the Internet of Things, the problem of automatic content interpretation appears as a major technical challenge.

In our experiments we found Semantic Web technologies, mainly RDF and OWL, a suitable means for objects to express their knowledge of the environment, enabling fellow objects to interpret this information and behave accordingly. There is no limit in the number of vocabularies than can be applied, depending on the knowledge domains objects must be aware of: semantic technologies are the appropriate vehicle to interpret the information provided by different heterogeneous sources.

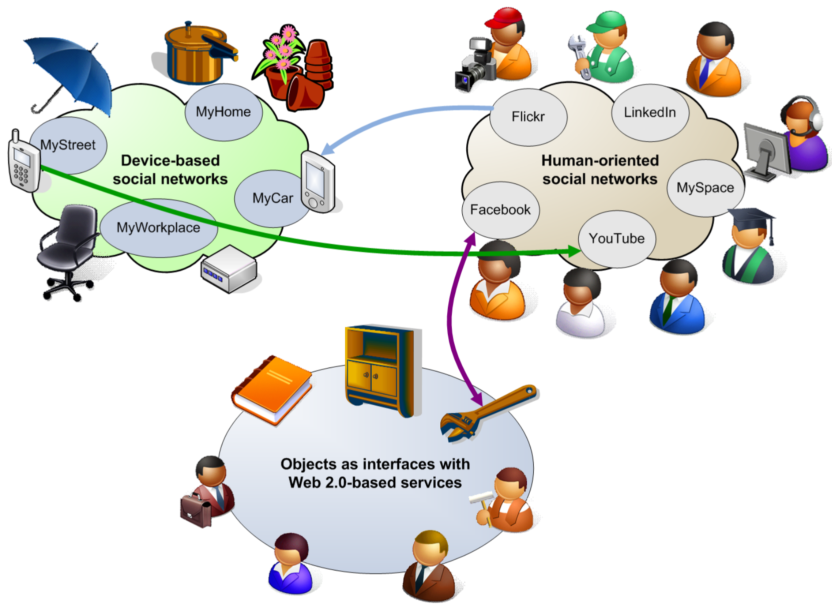

Fig. 6. Graphical representation of the three challenges for Web 2.0-enabled things.

For instance, in the Aware-Umbrella prototype, the "virtual weather sensor" that connected to the `weather.com` website semantized the weather information using a vocabulary the umbrella was able to interpret. This semantized weather information was made available to any object in the environment upon request. A similar model was followed in the SmartPlants prototype where a software component semantized the information provided by the wireless sensor network using lighting, temperature and location ontologies, and made it available to interested parties upon request.

While the SoaM architecture used in these scenarios promotes social collaboration among devices in an *ad hoc* way, Web 2.0 models fit perfectly here in order to obtain similar results in a more structured form. Instead of having the objects in the environment creating multiple communication flows to exchange information, an "environmental wiki" could act as repository of information about the environment, with multiple contributors that continuously update this wiki based on their perceptions and interpretations. Annotations in the wiki must still be made using Semantic Web technologies, which makes them difficult for humans to read, but very easy for devices to interpret.

There are two major approaches for the implementation of this "environmental wiki": a centralized approach based on a server in the environment with the semantic wiki software storing all the information; and a decentralized approach based on the wiki being stored in a distributed way, different parts in different objects with some kind of distributed searching mechanism. The later approach is similar to Tuple Spaces [14] or even Semantic Tuple Spaces [8], but with a wiki orientation.

Similarly, existing objects and devices generally maintain a log file with all the incidences that occur during normal operation. Access to this log file is generally restricted to administrators or special users. Just as people have transitioned from secret diaries to public blogs, in which users want to share their experiences, knowledge and opinions with everyone, we think that entities in the Internet of Things should follow a similar approach: creating blog entries using Semantic Web technologies so that objects can share their "personal" interpretations and knowledge. Microblogging (Twitter- and Jaiku- style) may be even more appropriate due to its brevity.

For example, we are working on an extension of the SmartPlant in which the plant creates blog entries in both human-readable and semantically annotated form, in order to share *feelings* such as "I feel lonely", "I am thirsty", "I need more light", or "It is dark and nobody is here", based on its interpretation of the environmental information provided by surrounding entities.

5.2 Objects as consumers and producers of content in existing human-oriented social networks

The second challenge for Web 2.0-enabled things consists on connecting them to existing social networks in order to consume and/or produce content in behalf of their users. This approach would result in new ways of interacting with social websites, different from the traditional method of using the web browser.

For example, we are working on an additional extension to the SmartPlant in which the plant projects a blinking green light everytime the user has a Facebook friend request waiting in the queue. Thus, instead of having to check the social network homepage every now and then, existing objects in the environment can perform the task for their users and react in different ways.

Since the RealWidget prototype is basically a wireless OLED display, we are also working on a particularization of this device based on connecting to `Flickr.com` using the user's account, and start a photo slideshow everytime there are new photos in any of the user's groups.

While people are more and more involved in social networking on the Internet, these examples illustrate the powerful capabilities of using physical objects to relieve users from continuously checking up-to-date information from these websites. Designing things that actively contribute with content in behalf of the user seems a bit more complicated, but equally feasible, specially for simple activities.

For instance in the SmartPlant prototype, the user could automatically accept the pending Facebook friend requests by simply touching a part of the plant's pot where a small touch sensor resides. While we are not planning initially to augment the SmartPlant with a small display, it can be useful in this situation so that the user can visualize the name of the friend and accept or deny the request at his will. Precisely, user interactions with social websites-connected things is the subject of the third challenge we have identified for future research.

5.3 Objects as interfaces with Web 2.0-based services

The major concern here is how to map user-object interactions to concrete actions on the social network. In the SmartPlant extension, is a green blinking projected light the most suitable means for alerting the user that he has some friend requests waiting? Is touching the pot the most appropriate means for indicating that the user accepts the requests?

Of course, a small display and keyboard in every object of the environment would eliminate any ambiguity about user interaction, but would also result in unnatural objects. Perhaps the most daunting challenge in having things connected to information sources on the Internet, and particularly to social websites, is how to map the information onto the object in a way that a user can intuitively understand, and even more difficult, how can user's interactions on the object be mapped onto concrete actions back to the website.

In the early experiments we carried out with the SmartPlant Facebook extension, we found that the user has to, obviously, have learned the interpretation of the blinking light previously as there is no natural mapping with its function. While this may be a problem if some concrete object has to express a plethora of different status or information updates using few interaction means, it is not such if there is only one simple function mapped onto the object as in the case of the mentioned Facebook extension. We consider this issue the most critical factor of success in order to design everyday objects that act as connectors with the user social life (on the Internet) in a natural way.

6 Conclusion

Devices should talk and share information without any geographical limitation, just as we humans do. Internet and the Web have demonstrated their ability for providing these capabilities to people, and also constitute the suitable means for enabling global-scale social devices.

This new wave of artifacts will exhibit social capabilities, e.g. promoting information sharing, recording individual opinions and interpretations about the context that can be easily accessed by others, tagging others' resources, or implementing voting and ranking strategies among themselves and the services they provide. As we described in this paper, Web 2.0 mechanisms are ideal candidates to be applied here.

We consider the concept of "social device" to be of foremost importance for creating smart environments. It comprises some of the fundamental aspects researchers have been looking for during the last years, especially intelligent and global context-awareness, and serendipitous collaboration even with remote objects and services.

In our research we investigated the foundations of this new wave of social objects that use the Internet for communication. We outlined their desired characteristics and designed experimental prototypes in several scenarios to demonstrate their functionality.

We also identified three main challenges in the research of social implications on the Internet of Things: the creation of social networks of devices in the environment based on semantic technologies, the connection of these objects with human oriented social websites, and the interaction challenges between virtual information and physical object characteristics.

This vision promotes the emergence of new scenarios in which surrounding objects become more interactive than ever before, being aware of the fact that the Internet is a natural extension of users' life.

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