A Web of Wearables

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Abstract
Wearables are becoming the next Big Thing, and it is clear that they will become increasingly integrated into the Web of Things, instead of just being standalone resources that are not linked into the Web. Such a Web of Wearables will make wearables as easily accessible as other Web resources, allowing new classes of applications and systems to use them. This Web of Wearables will establish an ecosystem noticeably different from the current Web with more ties to the real world, more ties to personal information and data, and more ways to interact with the real world. It remains to be seen which applications and systems will emerge, but the designs of today will have an impact on what is possible tomorrow, so we should strive to make sure that the ecosystem we design is open, extensible, and flexible.

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Introduction
Connected wearables will make a noticeable difference in the next decade of the Web. Network connectivity on the protocol level is an essential requirement to start combing

them into bigger systems, and this basic connectivity often is referred to as the *Internet of Things*. However, what matters even more is that these wearables will become part of the globally interconnected fabric of the *Web of Things*. The reason for this is that in order to achieve massive scale effects and allow serendipitous reuse of the data and services provided by those wearables, the foundations provided by *Web Architecture* [5] are necessary to make them discoverable and to provide self-describing interaction models.

While at first sight it may be tempting to look at the entirety of this new class of resources as "one interconnected superorganism", we argue that instead the better metaphor is to look at this development as natural growth of the ecosystem of the Web. In this growing ecosystem, new classes of applications and systems will be able to exist and thrive, because of a new class of resources being available to them.

However, this is not going to be fundamentally different from the developments we have seen over the past two decades. General-purpose search engines and more specific variations (such as travel or shopping services) have appeared, once the number of available resources (and the value of providing search-based access to them) reached the tipping point where operating these services did become economically viable. In terms of the Web of Things in general and wearables specifically, we may not yet have reached where the network effect has become noticeable. But application areas such as healthcare and urban transportation may soon reach the point where dynamics will be driven by rapid adoption of wearables.

Our main argument is that *resource-orientation* [3] will make the critical difference. Currently, many wearables are interconnected based on relatively closed models, either because of business decisions of the makers, or because of suboptimal designs. In the future, not only will wearables be accessible and actionable on the Web level, they will also be based on an architecture where it does not matter whether a device and its data history is available directly or through a proxy, as long as available resources are made available through linking.

A Web of Resources

One of the important lessons of the Web's success is that, in order for a platform to grow this fast and broadly, it needs to be application-agnostic. The Web in its human-oriented form (mostly just HTML content in its early days) did not make any assumptions about the kind of resources that were made available on it. This allowed natural and uninhibited growth, and any constraints making assumptions about specific application domains probably would have meant slower growth and less innovation.

So far the Web's main standardization organization, the *World Wide Web Consortium (W3C)*[1], has mostly refrained from making domain-specific standards (with a few exceptions). As a general strategy, this is probably a good decision, as the Web's role should be that of a resource-oriented interaction platform. On that platform, general-purpose standards should provide a framework in which interactions can take advantage of the scalability of the platform, and the flexibility of the services made available on it.

The *Web of Things* seems to be one of the buzzwords of 2014, and activities such as the W3C's "Web of Things Workshop"[2] are now looking into which parts of the Web

[1] `http://www.w3.org/`
[2] `http://www.w3.org/2014/02/wot/`

may need some attention to be better suited for "Things" in general, and thus wearables as one important class of those things.

As mentioned above, the challenge will be to clearly and cleanly separate the platform aspects from domain-specific ones. As one example, it is interesting to look at sensors. Various communities have created domain-specific description models for sensors. *Electronic Device Description Language (EDDL)* [4] focuses on industry automation scenarios, whereas *SensorML* [7] comes from a slightly different background, being rooted mostly in environmental sensing. Recent work in a W3C incubator group has created the *Semantic Sensor Network (SSN)* ontology [1], which is a foundation ontology for sensors in a more generalized way.

However, such domain-specific modeling probably should best be left to those communities who are active in these domains. Once there is critical mass, these communities will invest the effort to create and maintain ontologies to match their domains and needs, so there is no need for the Web community as a whole to focus on domain.

Instead, what we think might be more important and effective is to look at some of the general interaction patterns that might not be well-supported in today's Web, but might be relevant in a Web of Things. These interaction patterns then can be used as research challenges, where again there might be different standards, but over time, standards may arise, leading to more interoperability.

Challenges

Which problems should the wearables community tackle in order to provide the best possible environment for things in general, and wearables more specifically, to become interconnected and actionable on the Web? The following sections list a number of issues we have identified as challenging and worthwhile areas of research and development, and possibly standardization.

Interaction Fabric
One of the core questions of wearables is meaningful connectivity: Even when things are connected to the Internet, the question remains how to interact with them on the Web. One possible answer to this might be *Activity Streams*[3], but it remains to be seen if that approach works well for the domain of wearables, or whether other protocols might be proposed.

Push Services
While Web interactions are well-served by HTTP's client/server request/response pattern, wearables and other things might benefit from using other communications patterns, such as push-based messaging. There are proposals from a variety of areas, such as *MQ Telemetry Transport (MQTT)* [6], but from an architecture point of view, push messaging is not (yet) part of the Web platform.

Another interesting challenge is that of proprietary vs. open push services. Today's mobile platforms have their own proprietary push services (such as *APN* for iOS and *C2DM* for Android), but these do not work across platform boundaries. Is it possible that in the future, push services to mobile devices can be platform-agnostic (i.e., just use the Web platform)?

Resource History
Looking at wearables and sensors in general, it seems that services such as access to a resource's history, and maybe

[3] Briefly described in a position paper for the W3C's nascent Web of Things activities. [8]

more sophisticated services such as query and analysis features, might become useful across a large set of device classes. Also, services such as this might not be provided by the device itself, but rather by some recording or aggregation facility associated with the device. The ways in which devices and data-oriented services for those devices are made available currently are not standardized, and resource-orientation might help to solve this problem by interlinking the various "stages" of data-oriented services.

Decentralization
As devices and their data are made available, this should not imply a particular distribution in a concrete system. Some devices might record data themselves, whereas others might just emit data, and it is recorded somewhere else. In some cases, there may be various places where recording happens, and those different data-oriented services might provide different combined views of data from various devices.

This issue may also be a question of data ownership. The raw and complete data may only be available through a protected and strategically located service, whereas less detailed aggregate services are also made available in a less controlled way. This way, it is possible to implement data management scenarios in a variety of differently distributed ways, without the need to change the design of how they are made available.

Data Fusion
While resource history and decentralization are necessary ingredients in a Web of Wearables, it is also important to think of models of how services can interact with a combination of wearables and their data. This becomes particularly important in scenarios such as healthcare, where on the one hand archives and their locations may have to follow privacy and regulatory requirements, while on the other hand for certain diagnostic purposes some of the data should be made available for combined analysis.

The ability to flexibly store, manage, aggregate, query, and combine data from wearables will be one of the most critical aspects of the emerging ecosystem for a Web of Wearables. Only if the ecosystems is built in a way that allows both control and flexibility in where and how data is managed, will it be possible that through innovation and evolution, new classes of applications can emerge within the constraints of the existing ecosystem.

Merging the data from the Web of Wearables with other rich information sources such as urban environments or building automation will allow new solutions to emerge that we cannot yet envision. What we can envision already is that any architecture that does not allow for those various areas to be combined seamlessly will severely hamper our abilities to solve problems in a way that takes into account as much information as possible.

Annotation
Web-enabled wearables not only make the data of wearables available, they also make it linkable. This in turn means that annotating this data becomes possible. A possible scenario may be that of a heart rate monitor, where a lab or doctors can make annotations to identify episodes of arrhythmia. Providing linkage between the raw data and the diagnosis will allow more effective ways how diagnoses can be used later on for studies and other scenarios where access to the raw data may prove useful.

From a design perspective, this means that resources should be identifiable, which on the Web means through URIs, and possibly fragment identifiers. As a general guideline, this might just translate to provide guidelines

and design patterns and possibly even templates, so that developers of new media types understand how to best design the media types so that they become conducive to annotation.

Access Control
In all of the above scenarios, nothing has been said about the critical issues of (user) identification, authentication, and authorization. This of course is something that needs to be addressed, in particular when looking at wearables and the deep insights these will allow (and have) by becoming parts of our daily lives.

Questions of access and content control, including issues such as *Digital Rights Management (DRM)*, probably will not need to addressed specifically for the Web of Wearables. Existing models of authentication and authorization can be applied, and only if these prove to be insufficient, new models need to be developed.

Model Unification/Integration
While it is possible that the Web of Wearables will emerge and grow in a decentralized and seemingly chaotic way, it also is possible that over time, some unification of basic descriptions will emerge. The SSN work mentioned above would be one possible way of what such a foundation might look like. If the foundation is general and extensible, then it might allow new applications to emerge that aggregate and combine wearables in previously impractical ways.

The question of whether and how such a unification and integration will occur is similar to that of the B2B marketplaces from the early days of the Web. In this case, what eventually happened that instead of a shared global understanding of business-process-oriented information, various communities creates competing (and often overlapping) standards, and these now coexist in various large-scale B2B communities and networks.

Incremental Steps

It is pretty certain that the Web in 10 or 20 years from now will look different from what it looks like today. But this most likely will be because of new classes of resources becoming available, and new classes of applications and services becoming possible and viable because of these resources. Most likely, the fundamental architecture of the Web will not change radically, still relying on the architectural style of *Representational State Transfer (REST)* [2].

With wearables on the rise, the challenges listed in the previous section will need to be tackled in one way or another. In some scenarios (such as the currently closed systems of simple wearables know as "fitbands"), not all of them might matter or be tackled by manufacturer. In other scenarios (such as e-health), there might be a much bigger incentive to design open and extensible architectures.

In 2014 alone, the W3C is looking into two activities that matter for wearables: The Social Web Working Group[4] will look at ways how social data (which increasingly is tied to or augmented with data from wearables) can be shared across the Web, instead of being restricted to one centrally controlled platform. The "Web of Things Workshop"[5] mentioned above will provide a forum for researchers and companies, and might result in the formation of another working group.

Web architecture provides a robust platform on which

[4] http://www.w3.org/2013/Social/WG
[5] http://www.w3.org/2014/02/wot/

incremental steps can be taken. Other than URIs, pretty much anything on the Web is open to evolution, including HTTP as the interaction protocol, and certainly media types for representing resource state. This incremental change allows the Web to evolve organically, and the success of certain technologies is driven by adoption.

Conclusions

In this paper, we identify a number of challenges for the Web of Wearables. With wearables becoming parts of the daily lives of more and more people, making them networked beyond pure connectivity, and building applications based on this Web of Wearables, will extend the Web in ways that are hard to predict.

While it may be tempting to look at all wearables as one homogenous set of interacting devices, we think that the better way to conceptualize this emerging landscape to look at it as an ecosystem of resources. It simply extends the existing ecosystem of resources on the Web today, and will allow new classes of applications and systems to be built.

The better the design of the Web of Wearables reflects this ecosystem approach, the more open it will be. While it is hard to predict how exactly the Web will look in ten years, it is easy to predict that it will have evolved in ways which we do not yet clearly see. Our challenges are an attempt to focus our attention on some promising areas that might make a difference.

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