The 5th Dimension: Building Blocks for Smart Infrastructures

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Introduction

Incorporate computing power into everyday objects in order to make them "smart" often fails due to physical limitations. There's only so much room on a felt pen, for example, which might not make it possible to hold even a small scale computer and its battery.

One viable solution is to *link* a real-world object to a virtual representation, for example a Web page, using an id that can be affixed to the object, such as a barcode label or an RFID tag. Once the artifact is brought into the vicinity of a reader, some sort of terminal device (i.e., a desktop or portable computer) can then allow arbitrary storage and retrieval of information associated with this device. [1,2,3,4]

We propose to extend this paradigm from simple information containers that are (logically) attached to everyday objects, to the concept of an event-based infrastructure of semi-autonomous, highly mobile, "virtual counterparts" that exist in a ubiquitous infrastructure substrate (i.e. a runtime environment). These virtual counterparts not only act as information repositories for their respective real-world artifacts, but represent semi-automonous entities with a full range of interaction capabilities, supporting such important concepts as mobility, security and privacy.

Virtual Counterparts

Virtual counterparts form a sort of 5th dimension in addition to our 4-dimensional space-time: While two real-world artifacts usually interact in the first four dimensions (say, by being in close proximity with respect to their three space-coordinates, at the same moment in time), they can *additionally* and *independently* interact through their virtual counterparts as well.

One useful example of such an interaction in 5D would be the following scenario: two "smart" (i.e., tagged) books are taken off a shelf, packed into a bag and taken out of a room, presumably to be read later (let's ignore theft for now). The fact that both books are taken out of the room at the same time could allow both of these smart books to realize that the other book is probably somewhat related. Assuming a tag reader being installed at the door (very much like anti-theft devices in stores today), both virtual counterparts could be briefly informed about the close proximity (in respect to spacetime) of the other artifact. Obviously, since the books only pass the energy field of the reader for a few seconds, any form of action *on the tag* can only be minimal. In our 5th dimension, however, both virtual counterparts can sense, compute, and act on this information long after the books have left the reader's field, for example allowing them to query each other for a list of keywords and gradually computing relevancy vectors with respect to other books they "met."

Mobility

Since substrates – the ubqiuitous computing environments that these virtual counterparts exist and operate in – will be non-continuous and inhomogeneous (i.e., different runtime environments in different buildings, cities, countries), the infrastructure must support code mobility as a means for counterparts to travel between substrates. Although virtual counterparts act mostly autonomusly, the strong link to their real-world artifacts requires some form of substrate-based proximity, where each virtual counterpart needs to ensure that data can freely pass to and from its artifact. In areas with a low substrate density, this might require some form of hibernation for the virtual counterpart, for example by serializing it and writing it directly on the artifact's tag. Once the artifact enters an environment with substrate support, the counterpart can be reinstantiated.

Event-driven

The substrate requires a sophisticated, event-driven communication platform that allows sensors and actors in the real world (e.g., RFID reader and writer) to interact with these virtual counterparts. Substrates must offer both low-level as well as higher-order event systems which can, for example, notify virtual counterparts in real-time about the fact that their artifact is leaving the substrate range (which might require the virtual counterpart to serialize itself on the artifact), or collect multiple low-level events over time and fuse them into a single, high-level event at a later time.

Position Statement

We are interested in bringing about such a 5th dimension in order to enable real-world artifacts to become "smart things", and would like to discuss requirements, possibilities, and limitations of such an approach. Several projects in our group have initiated work on early prototypes, for which we hope to gather valuable feedback from the discussions at the workshop.

References

[1] Want, et al. "Bridging Physical and Virtual Worlds with Electronic Tags". Proceedings of CHI 99, May 1999

[2] Barrett, et al. "Informative Things: How to attach information to the real world."

[3] Minar, et al. "Hive: Distributed Agents for Networking Things"

[4] Kindberg, et al. "People, Places, Things: Web Presence for the Real World"