Single value devices

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Abstract: We live in a world of continuous information overflow, but the quality of information and communication is suffering. Single value devices contribute to the information and communication quality by focussing on one explicit, relevant piece of information. The information is decoupled from a computer and represented in an object, integrating into daily life. The contribution of this paper is on different levels: first, we identify the class of single value devices, and, second, illustrate it by examples in a survey. Third, we collect the characterisations of single value devices in a taxonomy. The taxonomy provides also a collection of design choices allowing to find new combinations or alternatives more easily, and facilitating the design of new, meaningful, effective and working objects. Finally, when we want to step from experimental and conceptual examples to commercialisable *products* a number of issues become relevant that are identified and discussed in this paper.

Keywords: ambient displays; calm technology; tangible interfaces.

Reference to this paper should be made as follows: Mader, A., Dertien, E., Kolkmeier, J. and Reidsma, D. (2015) 'Single value devices', *Int. J. Arts and Technology*, Vol. 8, No. 3, pp.249–277.

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This paper is a revised and expanded version of a paper entitled 'Single value devices' presented at 4th International ICST Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN 2011), Genova, Italy, May 2011.

1 Introduction

Internet provides an amount of information that exceeds everything known in history. The quality of information in Wikipedia surpasses every existing encyclopedia. News spread with incredible speed, allowing people to act quickly, which meanwhile is even a political factor. People are organised in social networks, increasing the quantity of information exchange and possibilities for communication. Mobile phones are omnipresent, and dominate public space more and more: people communicate via mobile phones all the time and everywhere, while shifting the borders of privacy. The covering of the world with networks increases, internet is accessible via telephone networks, and also wireless internet is available not only at work and at home, but also in cafes, stations, trains, and increasingly in all kind of public spaces.

In the end, we are overburdened by information.

As a consequence, it is more and more desirable to being exposed only to relevant information. Filtering the personally interesting items out of the abundance of information available is one aspect there. The other aspect is that the information should integrate in our natural environments, adapting to our perception abilities and aesthetic preferences, and relieve us from keyboards, screens and web-browsers whenever avoidable. Single value devices are designed to meet these two aspects. They extract only a single value of interest from the cloud of information, and display it in a physical object that has its own place in our environment. A person suffering from hay fever could get the pollen status from the internet: there are tables differentiating types of pollen, and their intensity at different places and different periods, continuously updated. A single value device designed for this person would display personalised, aggregate value: only the types of pollen that are irritating for our example person are taken into account, and also only the living environment of this person. These data are processed to a single value indicating how harmful it would be to go outside for our person. The display could be a nice object in the living room, changing its colour according to the intensity of harmful pollen outside. The person can look at this display object when she considers to go outside, and decide to take medicine, or using a respiratory protection, or avoid going outside.

With the definition above also a watch would be a single value device. However, as we want to benefit from the possibilities of internet while avoiding disadvantages, we consider single value devices as objects that are connected to the internet.

A single value can carry a huge amount of information. The single bit of information that a friend is online on ICQ creates an awareness of the other person, an emotion of sharing presence and activity, and may suggest an action, which is to contact the friend. Embodying the representation in a dedicated (everyday, or especially designed) object has additional advantages. Firstly, it brings more immediacy to the information, compared with opening a laptop, connecting to the internet and searching for the information. Secondly, dedicated objects allow for an almost unlimited variety of designs to represent the information and to interact with the user. Whatever can be invented using actuators and sensors, displaying or sensing sound, light, movement, and what people find easy and pleasant to perceive. As we will discuss later, it also gives more possibilities to design for *emotion*. Finally, dedicated objects, more than traditional screen-based devices, allow the technology and the information representation to move into the background or periphery. The information comes only into focus when needed, and the user is not overburdened with information.

Applications for single value devices are for communication, motivation, information, reminding, or creating awareness. They may be for home environment, offices hospitals or schools, they may be playful, aesthetic, personal, or generic.

The concept of single value devices has a potential that is not yet realised. Even though there are a number of existing examples, we do not find them back in our daily life. Therefore, the basic motivation for our work is to identify the ingredients that are necessary to make single value devices objects of our every-day environment. Next to a conceptual analysis, there is a whole range of questions from meaning and effectiveness, aesthetics and imagination to design, hardware and technology. Even if the technological concept of single value devices is feasible in principle, issues such as usability and internet connection have a number of requirements, that – if not solved – can break the application or leave it at the stage of a gadget or prototype.

Single value devices are part of a development that started in the nineties with the ideas of 'ubiquitous computing' by Weiser and Brown (1996); Weiser and Brown (1997), with the goal of "the non-intrusive availability of computers throughout the physical environment virtually, if not effectively, invisible or transparent to the user". We also share this idea of "getting computers out of the way" and the "definition and construction of new computing artefacts".

One aspect in ubiquitous computing is the shift to the background, that was further elaborated by Buxton (1995) and Ju and Leifer (2008). Applications remain in the background of consciousness and move only to the foreground when necessary or when the user shifts her attention to it. The original term 'calm technology' for this concept was also originated by Weiser and Brown (1996); Weiser and Brown (1997).

We see single value devices also in the context of tangible media of Ishii and Ullmer (1997), who aim at "coupling the bits with everyday physical objects and architectural surfaces". He emphasises the bridging between the two realms in which we live, "the physical environment and the cyberspace".

Also closely connected is research on peripheral displays by Matthews et al. (2004) and Eggen and Mensvoort (2009), where information abstraction and transmission, human perception, ways of notification and aesthetic feeling are addressed. The general concept addressed in this and other work is 'ambient displays' and 'peripheral displays', as elaborated by Pousman and Stasko (2006), of which single value devices form a subclass.

Single value devices can also be seen as representatives of the Internet of Things (Atzori et al., 2010). In a restricted definition the Internet of Things refers to RFID applications exclusively. We consider the broader definition, as networked everyday objects. Applications of single value devices, following the classification of Atzori et al. (2010), can be found in the personal and social domain, in the smart environment domain, and also in the healthcare domain.

The two main questions that structure this paper are: "What are single value devices?", and "How to make single value devices?". With respect to the first question, we present a survey with examples of existing single value devices, which provides a better understanding of the field and its range. In Section 3, we order the phenomena found in the objects of the survey, and suggest a taxonomy based on these. On one hand, this taxonomy makes the variety of single value devices more explicit, and contributes to our first question. Additionally, it is also a first step in answering the question how-to-make, as each class corresponds to a design decision that has to be taken. In Section 4, the focus is on the *design* of single value devices. We discuss a number of design aspects that we did not find in the examples of the survey, but that are relevant for the realisation and usability of single value devices in daily life. In more detail, we investigate requirements, suggest a hardware toolbox, a generic way for connection to the internet, and discuss the tension between personal meaning and generic design.

2 Survey of single value devices

In this section we present a survey of single value devices. The intention is to illustrate the field, and show the variety of possible applications and approaches. A classification of the phenomena found here will be suggested in Section 3, and the examples here will be used to illustrate the different aspects found. As the classification provides a structuring and ordering of the examples, we choose for this section a chronological presentation, which gives an impression how the field evolved.

The objects presented here are often prototypes, conceptual experiments, or results from art projects. Some are little documented, and not published as a paper. For most, it is not clear how the technological realisation was done, and if there is a working prototype. Only a few are commercially available. Still, altogether, they form the background and basis of single value devices.

The technology that was used to realise the examples in the survey is explained in the literature for some cases. For many examples only the concept was described. Therefore, we could only add a short description of the technology used where available.

- *Feather*, *scent* and *shaker* (Strong and Gaver, 1996) are pairs of objects shared by two people. In 'feather' and 'scent', one partner has a picture frame, and shows (s)he thinks of the other by shaking the frame. This message of connectedness is communicated to the partner at home in a manner reflecting the transience of thought: through a feather in a cylinder that is lifted by a little fan, or by vaporising essential oil in an aluminium bowl using a heating element. 'Shaker' is meant for less intimate friends, and consists of a pair of hand sized devices that, when shaken, cause a vibration of the other object.
- The *dangling string* (also called *live wire*) (Weiser and Brown, 1996) is an installation with the goal to make 'bits' visual, physical and hearable, and is located in an office environment. It consists of one and a half meter of plastic spaghetti hanging from the ceiling, mounted to a small electric motor. The motor is triggered by the activity on an ethernet cable. A very busy network causes a madly whirling string with a characteristic noise; a quiet network causes only a small twitch every few seconds. Placed in an unused corner of a hallway, the long string is visible and audible from many offices without being obtrusive.
- As part of the *ambient room* (Ishii and Ullmer, 1997) an installation was created that transforms the activity on a webpage to a pattern of water ripples projected on the ceiling. A solenoid-driven float triggered by 'bits' of web activity creates ripples on the surface of the water in a tank; these ripples are reflected on the ceiling using a strong light. The projection is a very subtle and unique display. The intention of the installation was to elaborate the shift of attention between foreground and background. It is one installation in a series, 'tangible bits', that wants to bridge between physical and digital world by augmenting physical objects and environments with digital information.
- Developed for a working environment is the light installation of Gellersen et al. (1999). Posters of research projects on the corridor walls are illuminated, each by its own spotlight. The light intensity of each spot is determined by the number of hits on the corresponding project webpage. In contrast to the ambient room example, not only the actual hits are visualised, but their aggregate over a period of time.

- The *surrogates* of Greenberg and Kuzuoka (1999) are a number of examples how presence and absence of a remote person can be visualised. The examples are meant for a working environment. A little figure turns its face to the wall if the person to which it is connected is not present in her or his office, and turns it front to the room, if the person is available. Another example from this series is a dragonfly that displays presence and activity of the remote person by movement of its wings, visibly and audibly. When the remote person is absent of inactive, the movement of the wings stop. A relevant issue in the design of these objects was privacy, that is preserved by abstraction of most parameters apart from pure 'presence'.
- Nonnogotchi (http://www.doorsofperception.com/archives/2000/01/design_and_elde.php) consists of two communication devices, for a grandchild and a grandparent. Messages are sent to remind the grandparent to take pills or to measure blood pressure. When the grandparent's device has been silent for too long, the grandchild would get an alert, such that the grandchild can contact the grandparent.
- *White stones* (Tollmar et al., 2000) is a non-verbal communication device for couples, an example for 'telematic emotional communication'. A touch or temperature sensor can detect when one partner takes a white stone in his hand. This causes a coupled remote white stone to produce a sound. When the remote partner takes her stone into her hands, a message is sent back triggering an internal heating device in the other white stone. The white stones are one in an explorative series of objects, as are the two following two, that have the goal to provide insight on communication artefacts.
- *Soft air communication* (Tollmar et al., 2000) belongs to the same series and topic as the white stones, trying to make physical presence visible on a pair of chairs. In the chairs are sensors for weight and movement. The sensor signals of one chair are displayed on the remote chair by light and sound, giving the illusion of the presence of another person.
- The *frame* (Tollmar et al., 2000) indicates presence or absence of family members. A photo in the frame rises when the respective person is at home, or is dimmed otherwise. A receptor on a key ring or in a wallet captures the presence of the person.
- The *kiss communicator* (Buchenau and Suri, 2000) is an object for couples. It includes two devices, connected wirelessly through internet. The sender can blow on her device, which is displayed as a colour sequence on the other device, and visible only for moment.
- Also designed for partners is *LumiTouch* (Chang et al., 2001) is a pair of picture frames that are connected to a computer and may contain the photo of the partner. The frames allow for two modes of interaction: in a passive one movement is detected which makes the other frame glowing. In the other mode a frame can be squeezed giving a different light effect on the other frame.

- Internet Tea Kettle (http://www.mimamori.net/) tells adult children whether parents no longer make tea, i.e., do not use the tea kettle. Making tea regularly is an inherent element of normal daily activity in the Japanese culture, and making tea therefore indicates that the day passes in a normal pattern. When the internet tea kettle is not used, it will send an email to the children reporting the irregularity. The children can then get in contact and inform what the reason is. In home care there are a number of projects where houses are equipped with sensors, and learning applications train the regularities to identify irregularities in emergency situations. The internet tea kettle falls in this sense in this area of applications. However, it uses a pattern that is already a part of the culture, and by having only one, quite restricted sensor, the privacy of the parents is preserved. It is one of the few examples that is commercially available [see also Figure 1(a)].
- The *ambient orb* (http://www.ambientdevices.com/cat/orb/MAN Ambient Orb 3-23-03.pdf) is a light ball indicating real-time price of energy. It can be configured via a company website to display other information, and is meant as an object for managers and business people, with the intention to visualise relevant data much more direct and intuitively than graphics could do. The ambient orb has a very elegant, but also neutral appearance. In general, it is suitable to display different kinds of information. It is a commercial product. Connection is through a radio data network, which is, as far as we know, unique in this list of single value devices.
- The *data fountain* (Eggen and Mensvoort, 2009) in Figure 2 can display stock market information by the height of a water fountain. In the example given, the different heights of three vertical water jets reflect the relative exchange rates of the Yen, Euro, and Dollar. The data fountain is one example in a range with the aim to design information displays for environmental awareness.
- The *fishtank* (Tellart Humana fishtank, http://www.tellart.com) shown in Figure 1(b) is designed for a health stimulation project. It tries to motivate people to move more by a competitive factor. The setting is for employees of a company, who all wear a pedometer counting their steps. Each employee has also her or his own virtual fish in a virtual fish tank. The fish tank is displayed on a big public screen. A fish representing an employee grows with the amount of movement of this employee as measured by the pedometer. Everybody can see whether a colleague has a big fish, and lives more healthy accordingly, or just a tiny little one, showing that she or he lives less healthy. The fishtank is in the narrow sense not a single value device, as it displays a number of single values, nor is the screen really physical. Still, it is a relevant example by the competitive element and the motivation for healthy behaviour.
- Nabaztag (http://www.nabaztag.com) is a networked robot rabbit with speech, movable ears, coloured LEDs, RFID reader, etc. A whole range of applications can run on a Nabaztag, including radio streaming, RFID-based messages and aggregated weather information. In this sense the Nabaztag does not really belong to the single value devices. However, focussing it to ear communication, we want to include it as an original way of message transfer. Two nabaztags can be married. When the ears of one Nabaztag are brought in a certain position, the partner Nabaztag automatically puts his ears in the same position. The ear

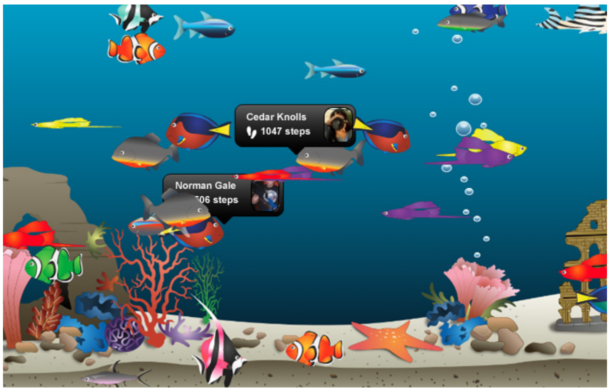
positions allow, in principle, for a small language of message exchange, agreed between the owners of the Nabaztags.

- The *flower lamp* is one of the objects designed in a series that have the aim to increase awareness of energy and power consumption (Backlund et al., 2006) in a home environment. The flower lamp opens up to bloom depending on the energy consumption at home: the less energy is consumed the more the flower opens.
- The *hug shirt* (http://www.cutecircuit.com/products/thehugshirt/) allows to send a hug via SMS to a mobile phone of the person wearing the hug shirt, and via blue tooth the hug is transmitted to the shirt. Sensors in a hug shirt can capture heart beat, skin temperature and strength of a hug, actuators can physically reproduce these information. The hug shirt is a commercial product.
- *Blossom* (Seymour, 2008) in Figure 3(a) is a very personal object for a woman reflecting her connectedness to her family roots in cyprus. The blossom is made of stamps that were sent from Cyprus to England at the same time as her family emigrated. It opens when a predetermined amount of rain is detected by a sensor on the family land in Cyprus. The blossom opens only once to reflect the uniqueness of events in contrast to continuous availability of services.
- *Journeys between ourselves* (Seymour, 2008) in Figure 3(b) is a pair of necklaces designed for a mother and adult daughter. When one touches her necklace the other's necklace starts trembling softly. The necklaces are very personal objects made for specific persons, where the design refers exclusively to shared memories of mother and daughter. As in the previous example, one intention of the design here was to make a position explicit, opposite to mass consumer electronics.
- *BioMedia* (Salem et al., 2008) use plants as information display. Health, shape, pigmentation or bioluminescence of living organism should reflect, e.g., the user's health status. Lack of water is one possibility to control the shape of a plant as shown in Figure 4.
- The *Smart Umbrella* (Vazquez and Lopez-De-Ipina, 2008) gives a voice alert if two events take place: its owner leaves the house without taking it, and rain is predicted. For that purpose, the Smart Umbrella combines two types of information: from the internet, the weather forecast (weather.com), and the local, personal information, which the state of the door indicating whether someone is about to leave the house.
- The *Babbage Cabbage* (Fernando et al., 2009) uses a red cabbage as display. The acidity level of the feeding water can be modified, changing the colour of the cabbage between violet, purple and green. The cabbage has been used as single value display, with the colour of the cabbage representing information such as health of family members, or the quality of global climate and environment.

- *E. coli* (Cheok et al., 2008) are living micro organisms that, by transformed DNA, have the ability to glim. The intensity of their glow depends on input fluids. Consequently, by controlling the inputs fluids according to the value of data of interest, such as the health status of a family member, or ecological information, the E. coli can be used as displays for a single value.
- A playful competition device is *ikWin: google battle* (Roest et al., 2008), consisting of two platforms that can be extended to a couple of meters height. Two people can compete by getting on a platform each, and then giving their name as input. The number of google hits will move the platform up, and the one with more google hits will end up in a higher position.
- *Pairs* in Figure 5 (Cottam, 2009) is also meant for partners. Two paired objects tremble with increasing intensity when they come closer to each other, and stop if they are put together. Much attention is put on the objects themselves, made from wood, such that it is a pleasure to touch and put them together. Additionally, effort was put in giving them an individual look and personal history. Technology used includes arduino and wireless internet connection.
- *Scottie* (Bonn, 2009) is designed for non-verbal communication between children in a hospital and their relatives. Child and remote relatives receive a doll each. Sending messages is done by shaking the doll or knocking on it, messages received are transformed into vibration and colors. Technology used includes arduino, Bluetooth, and mobile phone.
- Tactile communication between remote parents and their children is supported by the *huggy pajama* (The et al., 2009). It consists of a doll equipped with pressure sensors, to be hugged by a parent, and a haptic jacket, where, by air pressure, the sensation of a hug can be reproduced, as shown in Figure 6.
- The *internet enabled furby* (Dertien, 2009) is an example of an instrumented toy, which functions as room observer (light sensor) and primitive communication device (ears). It has an ethernet connection and is controlled by an arduino.
- The *fridge magnets* (Kolkmeier and Pelt, 2010) can indicate the time remaining for breakfast, before one has to leave to work. They take the way from home to work into account, using Google maps, the actual traffic information on this way, and also the individual time when work has to start. The fridge magnets are result from a students' project in 'creative technology'.
- The *Coconatch* (http://www.coconatch.com) is designed as physical warning device for twitter (see Figure 7). It can alert a user with sound, movement and light about new messages. Messages can be sent back by squeezing the Coconatch. The device is connected to a PC using a USB connection. The PC runs a tiny server application to connect the device with Twitter trough internet.
- The *message alert* (van der Heemst, 2011) is located in an rest home to stimulate social interaction between inhabitants. People have devices at their rooms that indicate when there are new messages at the central message board. This knowledge motivates people to go to the message board, meet there and get in contact.

Figure 1 Yet two more examples of single value devices, (a) the Internet Tea Kettle sends a mail when not used regularly (b) the virtual fishtank shows big fishes for employees who move a lot, i.e., live more healthy (see online version for colours)

(a)



(b)

Figure 2 The data fountain displays the exchange rate of Yen, Euro, and Dollar (see online version for colours)

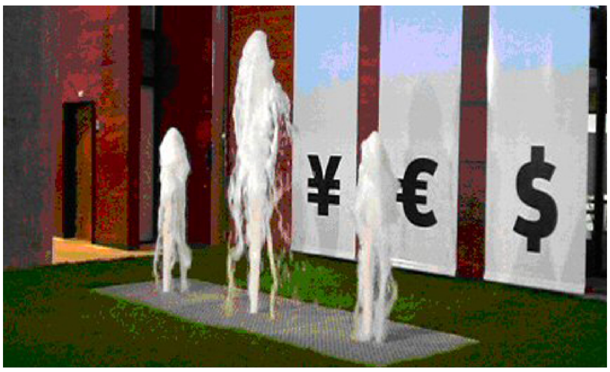
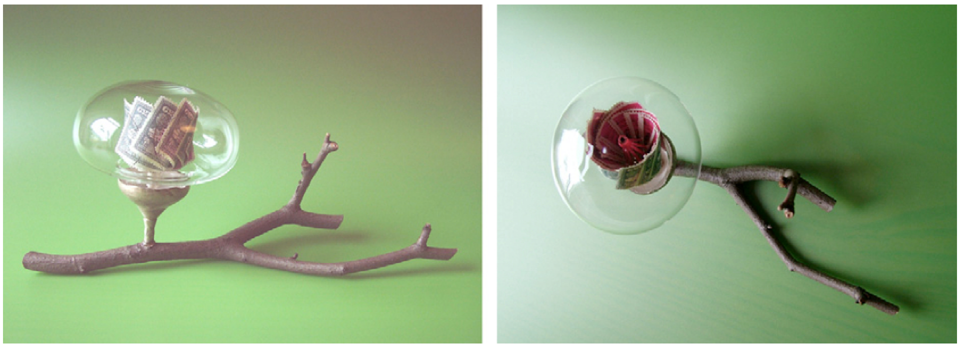


Figure 3 Two single value devices by Jayne Wallace, (a) the Blossom opens only once, when there is sufficient rain on the family ground in Cyprus (b) the necklace gently trembles when one thinks of the other (see online version for colours)



(a)

(b)

Figure 4 The shape of the plant gives information about the heath status of its owner (see online version for colours)

Figure 5 Pairs are two objects for partners that tremble when coming closer, and are quiet when together (see online version for colours)

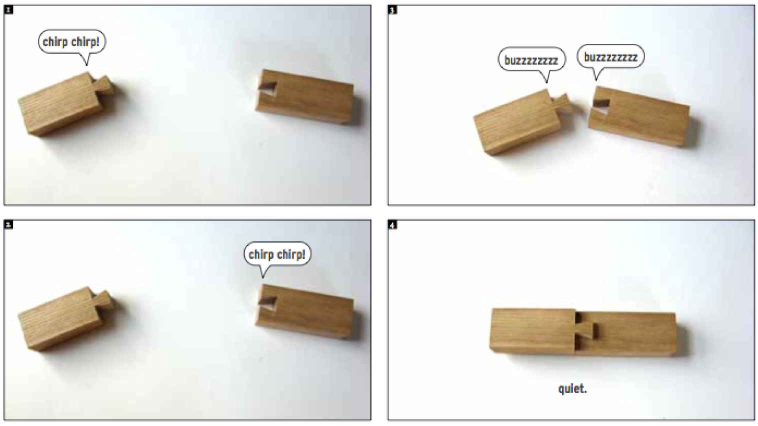


Figure 6 With the huggy pajama the sensation of a hug can be transmitted (see online version for colours)

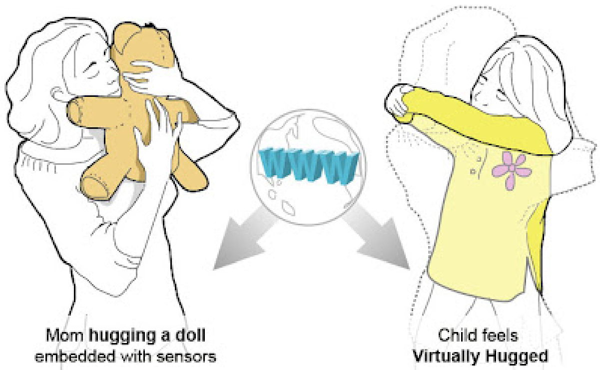


Figure 7 The Coconatch is a physical twitter alert (see online version for colours)

3 Taxonomy of single value devices

The application range of the single value devices presented in Section 2 is broad. Many examples concern connection to your loved ones, as simple presence awareness devices [the frame (Tollmar et al., 2000), Internet Tea Kettle (http://www.mimamori.net/)], or active communication devices [e.g., journeys between ourselves (Seymour, 2008), The huggy pajama (The et al., 2009)]. Other examples focus on displaying practical information about one's environment, such as The Smart Umbrella (Vazquez and Lopez-De-Ipina, 2008), and the Babbage Cabbage visualising environmental issues (Fernando et al., 2009). Communication technologies range from internet to GSM text messages; some devices are realised as mass-producible objects whereas others are highly individual, one-time objects, exploring conceptual, artistic or technological possibilities. The goal of this section is to extract and to order the characteristics of the examples in the survey, for a better understanding of the scope and potential of single value devices. Closely related to our work here is a taxonomy of ambient information systems by Pousman and Stasko (2006). As they also observe, the characteristics found are a first demarcation of the design space: when designing a single value device for each of the characteristics a decision has to be taken. In this sense it can serve as a stimulation to reflect on choices made, to help in finding alternatives, to explore new combinations, and to identify white areas in the space of possible designs.

The taxonomy in keywords is contained in Table 1 which will be elaborated below.

Table 1 The taxonomy of single value devices in key words

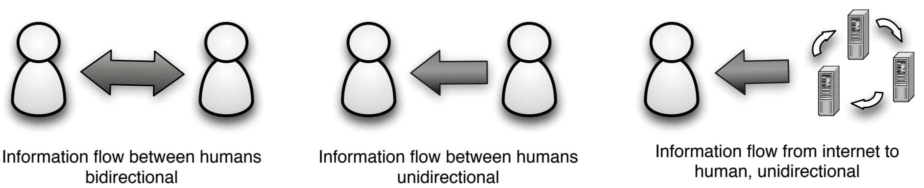
What are the characteristics of the information displayed?	
Information direction and communicative intent	
Information distance	
Information privacy	
Information decoupling	Physical, geographic, temporal
Information source	Sensors, databases and statistics, aggregators
What is the aimed impact of the information?	
Awareness	
Action	
Emotion	
What physical object is used?	
Dedicated object	
Display modality	Light (patterns), colour, sound, smell, motion, trembling
Object relation	Individual, configurable, generic (mass) product
What hardware technology is used?	
Actuators	LEDs, dimmers, speakers, inflatable components, (vibration) motors, heaters, bimetal, pumps, etc.
Sensors	GPS, accelerometers, distance sensors, RFID, sound intensity, light intensity, temperature, humidity, pressure (touch, air, height), time, etc.
Information transport	microcontrollers, PCs, USB, WLAN, phones, web servers.

3.1 What are the characteristics of the information displayed?

3.1.1 Information direction and communicative intent

The flow of information may be between two humans (social information), or human and machine (Buxton, 1995) as illustrated in Figure 8. When an explicit *communicative intent* is involved, the connection will always be between humans, and may be unidirectional or bidirectional. Examples are Bonn (2009) and the necklaces (Seymour, 2008). In contrast, *status information* is unidirectional, and may involve human-machine as well as human-human connections (note that the elderly relatives using the Internet Tea Kettle do not make tea *in order to* communicate this fact to their family members). Other examples are the data fountain (Bakker et al., 2010) and Smart Umbrella (Vazquez and Lopez-De-Ipina, 2008). The photo frame LumiTouch (Chang et al., 2001) contains both aspects: it gives status information by detecting movement, and it allows for communication by squeezing the frame.

Figure 8 Information directions and participants



3.1.2 Information distance

Information distance represents, for social information, the social distance between the information source and the receiver. It can be described as shells spanning from self to family to society and world (Fernando et al., 2009). Examples for the shell including the self are devices that measure and manage data of movement for health reasons, with the goal to stimulate to do more sports. For the family shell there are a number of examples in the survey: the white stones (Tollmar et al., 2000), the necklaces of Journeys between ourselves (Seymour, 2008), the picture frames of LumiTouch (Chang et al., 2001), and more. Examples for the society shell could be the Coconatch (http://www.coconatch.com) of a school kid, indicating when there are tweets about school tagged with examination information, for courses, or going out with school mates. On the level of the world shell, an example could be stock market information as displayed in the ambient orb (Ambient orb, xxxx) or the data fountain (Bakker et al., 2010).

3.1.3 Information privacy

The information represented by the single value device may be *public*, e.g., taken from the internet, or *private* which includes everything that has (or should have) only personal use. Public information are typically environmental data, or the pollen status at a certain location, traffic conditions, etc. Most human-human connections fall in the latter category of private information, as the Kiss Communicator (Buchenau and

Suri, 2000), or the picture frame (Tollmar et al., 2000). The Smart Umbrella (Vazquez and Lopez-De-Ipina, 2008) combines both: the information that someone is leaving the house is private, the weather information is public. Also the fridge magnet (Kolkmeier and Pelt, 2010) combines private information, which is my route to work, and public information, the traffic situation along this road.

3.1.4 Information decoupling

A simple watch is also a single value device. However, when we look at the class of objects in the survey, they typically involve one or more aspects of decoupling, which we consider as a basic characteristics of single value devices.

3.1.4.1 Physical decoupling

The displayed quantity is not necessary one single physical measurable phenomenon such as temperature, but can also be an aggregate value. For example, the 'state of the global environment' displayed by the Babbage Cabbage (Fernando et al., 2009) is a complex aggregate of many information sources.

3.1.4.2 Geographic decoupling

Network communications allow us to completely decouple the display and the measured data geographically. Blossoms (Seymour, 2008) are an good example: the blossom in England opens depending on rain quantity on Cyprus.

3.1.4.2 Temporal decoupling

The values displayed need not be strictly related to real-time (as in 'here and now'). The project posters spot lights (Gellersen et al., 1999) display historical data. Other devices might, e.g., target awareness of changes in bodily health over time, or engender historical awareness by showing the climate at a certain location, ten years in the past.

3.1.5 Information source

3.1.5.1 Sensors

Communication devices typically obtain their information from sensors in the paired object [e.g., LumiTouch (Chang et al., 2001), the white stones (Tollmar et al., 2000), and the kiss communicator (Buchenau and Suri, 2000)].

3.1.5.2 Databases and statistics

Data available on the internet is another information source. Examples are the data fountain (Bakker et al., 2010) displaying currency exchange values, the Nabaztag/Karotz (http://www.karotz.com) indicating the weather by light patterns, or even Coconatch (http://www.coconatch.com) that receives the information about tweets from a database. As said before, the single values that are displayed need not correspond to a single value that is 'measured'.

3.1.5.3 Aggregators

Aggregators can combine information in various ways, ranging from very straightforward to highly complicated information fusion using intelligent learning algorithms. An example for simple aggregation is the Smart Umbrella (Vazquez and Lopez-De-Ipina, 2008). A learning algorithm could learn more individual patterns for people than, e.g., in Internet Tea Kettle (http://www.mimamori.net/) example, and give alarms to relatives more reliably.

3.2 What is the intended impact of displaying the information?

In the first place, all devices create *awareness*: your partner thinks of you; your parents make tea [and therefore apparently are active (Internet Tea Kettle, http://www.mimamori.net/)]; or the device makes you aware of the CO_2 emission ten years ago, compared to today. The consequence of awareness is an action or an emotion (Csikszentmihalyi and Rochberg-Halton, 1981).

3.2.1 Action

Some information suggests an action. For example, the Peek-Aa-Boo Surrogate (Greenberg and Kuzuoka, 1999) might trigger you to drop by in your colleague's office. Other single value devices may stimulate one to water a dry plant, go to the coffee room when others are there, make a break, read your tweets, phone your parents. Measuring and displaying personal health status can motivate people to live healthier, as with the fishtank (Tellart Humana fishtank, http://www.tellart.com). The message alert in a rest house (van der Heemst, 2011) stimulates interaction between people.

3.2.2 Emotion

Other information aims at triggering emotions. This often concerns relations between people – as with the various partner devices – but another emotion might be, e.g., *feeling rich and important*, through a personal stock market indicator, or the number of tweets received.

3.3 What physical object is used for the single value device?

3.3.1 Is the information displayed through a dedicated object?

Most examples use dedicated objects, already existing or created for this purpose. A few, however, use walls and surfaces (Ishii and Ullmer, 1997) or dedicated screens (Tellart Humana fishtank, http://www.tellart.com) for display.

3.3.2 What is the modality used for displaying the information?

Any modality can be used (and: has been used) to represent the information in a single value device, for example:

- light intensity, as in the poster illumination example of Gellersen et al. (1999)
- light patterns, as reflected from water ripples in Ishii and Ullmer (1997) and Nabaztag (http://www.nabaztag.com)
- colour, as with the cabbages in Fernando et al. (2009)
- sound, as for the white stones (Tollmar et al., 2000)
- smell, as in the installation of scent (Strong and Gaver, 1996)
- motion, as with the dangling sting (Weiser and Brown, 1996)
- bubbles in a tube (Heiner et al., 1999)
- trembling, as in the Pairs, or the necklaces of 'journey between ourselves' (Cottam, 2009; Seymour, 2008).

This question is closely related to the characteristics 'notification level' in Pousman and Stasko (2006). There, the point of view is on the level of degree in which a user is interrupted by a ambient and peripheral information system, i.e., the perspective is not the pure descriptive one as we take here, but considers the effect on awareness. The different levels distinguished there are: *ignore, change blind, make aware, interrupt* and *demand attention*. Obviously, the various modalities can have a different impact in this context.

3.3.3 Object relation – how personal is the object?

Some of most evocative examples of single value devices are completely *individual* objects. For example, the necklaces and Blossom (Seymour, 2008) are pieces of art made for individual persons, by exploring what is meaningful to these persons and their relationships and transferring that into a very personal object. *Configurable* objects allow one, to some extent, to personalise a mass produced object object. For the Nabaztag differently patterned ears could be chosen, and there was a great variety of costumes for Nabaztags. A few single value devices are based on *mass produced* consumer electronics gadgets, and their physical appearance is hardly configurable.

3.4 What hardware technology is used?

Single value devices use a wide range hardware technologies.

3.4.1 Actuators

In our examples, (LED) lamps are used (Chang et al., 2001; Ishii and Ullmer, 1997), dimmers (Gellersen et al., 1999), speakers (Nabaztag, http://www.nabaztag.com), inflatable components for haptic sensations (The et al., 2009; Hug shirt, http://www.cutecircuit.com/products/thehugshirt/), motors (Weiser and Brown, 1996), vibraton motors (Cottam, 2009; Seymour, 2008; Nabaztag, http://www.nabaztag.com; Greenberg and Kuzuoka, 1999), heaters (Strong and Gaver, 1996; Tollmar et al., 2000), also using bimetal (Seymour, 2008), and pumps (Bakker et al., 2010; Heiner et al., 1999). The biological displays as in Babbage Cabbage (Fernando et al., 2009) or the fluorescent E. coli of Cheok et al. (2008) are a special kind of natural actuators.

3.4.2 Sensors

Sensors in the examples measure quantities such as location (GPS), displacement (accelerometers, distance sensors), presence of objects (RFID), sound intensity, light intensity, temperature, humidity, pressure (touch, air pressure, height), or time (DCF, GPS).

3.4.3 Information transport

Information is communicated through PCs, Arduinos or other microcontrollers, USB, WLAN, phones, wires, and web servers.

4 Design

The first part of the paper was concerned with the question *What are single value devices?* This section focusses on the question *How to design single value devices?* This concerns both the process and design issues, and the possibilities for developing generic solutions in form of a supporting toolbox.

Underlying single value devices is a fundamental tension. On the one hand, their most important characteristics centre on being highly personal and context dependent objects, to which people attach individual emotional meaning. On the other hand, commercially feasible production requires very different design decisions, like uniformisation.

The taxonomy in Section 3 does not only describe existing examples, it also implies what kind of decisions have to be taken when a single value device is designed: for each of the characteristics a design decision has to be taken, either explicitly or implicitly. In this sense, the taxonomy can also be used as a first design checklist or guideline. Furthermore, the characteristics can also help to identify combinations that have not yet been explored. In this section, we want to extend the design aspects implied by the taxonomy. We see that, although the concept of single value devices has already been around for a couple of years, we do not have them in our environments, nor find them in the stores (apart from very few exceptions). One reason is, that most work so far has still restricted itself to conceptual design, where the technical realisation consists just of a single prototype. To get a step further, however, a number of technical questions have to be addressed: even if it is feasible in principle to build single value devices, it requires also non-trivial technical expertise to realise them and make them practically usable. When these issues are not solved in a robust and easy way, this can break the whole application. In this section we suggest a toolbox solution including network connections and internet access.

Altogether, this section approaches some design questions that have been missing so far. Firstly, we discuss the different stakeholders and requirements. Secondly, we dive into technical aspects and proposing a toolbox solution. Thirdly (and finally), we elaborate the design decisions between personal and generic design of single value devices.

4.1 Requirements: stakeholders and global requirements

In order to identify requirements, we have to investigate who the stakeholders are and what they needs are. We need to know to whom it matters how easy it is to design interesting single value devices and, and to whom it matters how usable the end result is.

We distinguish three main classes of stakeholders. Firstly, there are the end users who actually obtain single value devices and use them in their daily life. Usability is a key concern to them. Secondly, there are the developers who conceives of an idea for a single value device and wants to design, build, and test it. Key concern here is the fact that the developer is generally not an electrical engineer or computer scientist. Thirdly, there are the producers. If a single value device is really worthwhile, it becomes interesting to bring it to market, either in small serial production or in mass production. We elaborate a bit more on these three groups of stakeholders below.

4.1.1 End users

End users already form a diverse group, concerning their technical abilities. For all of them, however, simplicity of usage is relevant. This includes

1 a simple introduction procedure to local internet or networks

2 an automatic way of coupling paired objects

3 automatic updates of applications and services

4 simple charging.

While many users might not want to configure their single value device, but use it straight away, some may be interested in a certain level of configuration. There is a number of applications that is only interesting for a specific period of time. The pollen status for my specific allergy profile, e.g., is only relevant in spring. In the summer we might be interested in water quality of the local lake. A couple of weeks before holiday one might want to know the temperature at the holiday destination, after the holiday that is not any more interesting. The energy consumed by heating your house is only relevant during the winter, etc. To configure a single value device for this class of examples a user must be capable to visit a website, choose a configuration, or, more advanced, create one, and make it effective for her or his device.

4.1.2 Developers

Single value devices can be used for a broad range of applications. One application area is, e.g., e-health, where they can help to visualise information and stimulate certain behaviour, for both, professionals or patients.

Potential developers for single value devices have in common that they are generally specialised in some application domain, for which they invent instances of single value devices. They typically do not have the extended knowledge of electrical engineering and computer science required to engineer objects from scratch.

Another requirement is that developers must be able to easily build different prototypes in small series, that can be evaluated with users in an early stage of their projects. For prototypes used by real users (e.g., in the e-health example: patients), it is also necessary that the prototypes are in a certain level of stability.

4.1.3 Producers

Cheap production has high production numbers as a condition. However, are often not to be produced in very large numbers. In order to still achieve reasonable prices, it is necessary to at least have cheap components. A requirement of potential single value device producers will therefore be that generic components are identified that can be produced in high numbers and that therefore are (relatively) cheap. This requirement and solution suggestion will be more elaborated in the toolbox approach below.

Permanence of service availability is a topic that is often overlooked in the development of prototype single value devices, but which is very important when they are to become commercial products. Objects are made that depend for their whole life cycle on paid connectivity services such as telephony networks, radio-data network or internet. Additionally, many devices need a webserver for registration, configuration, storage of data, and dedicated applications. A service model addressing quality of service, regular updates, and sufficient variation in the available applications is a crucial factor in the commercial success of a product.

4.2 Technology support issue: toolbox

Single value devices are not hightech products, in most cases. They are built on existing technology, and the development challenge consists in creative integration of technology and in the identification of useful, playful and aesthetic applications. However, even if the technology already exists, and is usable *in principle*, it still requires an advanced level of electronics expertise and knowledge of internet access to make objects really work. The group of people who have an interest in designing single value devices, such as the developers described above, contains certainly many who are not experts in these technological domains. Moreover, a number of problems and their solutions are appearing repeatedly. We see therefore the challenge to identify construction patterns and generic solutions that can be sorted out and described in such a way that they are easy to reuse. This aspiration leads to the concept of a toolbox solution, making standard components more accessible to designers whose expertise is more on the application side than on the the technological side, and we especially have user-designers in mind, as described in Section 4.1 above.

A different interest in reusability of generic components comes from economical considerations. Each instance of single value devices will presumably not be produced in huge numbers. To make them still affordable, it is necessary to identify standard components that can be produced in high numbers and for a lower price. Otherwise single value devices will remain isolated art and conceptual experiments.

4.2.1 Hardware

Most single value devices require a similar set of technical components: a combination of sensors, actuators, control, power and connectivity. Hence it makes sense to assemble a toolkit containing a range of options for said components in order to facilitate design and development of new devices, also by people other than electrical engineers and interaction designers. Existing toolkits in this area such as the Peripheral Display Toolkit (Matthews et al., 2003) target part of the requirements (sensors, actuators, control) – however, power and connectivity are underemphasised.

4.2.2 No PC

Connecting single value devices to a PC or laptop might be a logical solution for providing power and (internet) connectivity. A device like Coconatch (http://www.coconatch.com) can be considered a single value device while being connected to a PC trough the USB port. However, it will only work when the PC is turned on. We feel that permanent connection to a PC is an obstacle to single value devices becoming truly background technology. Therefore we consider the technical requirements for single value devices that they have to function as ’stand-alone’ device.

4.2.3 Toolkit

Two approaches can be identified. On the one hand, one can assemble the hardware selecting components from the stated categories individually. On the other hand, one can aim for a ’swiss army knife’ solution: one set of electronics, or one module, that has sensors, actuators, connectivity, power and controller built-in, and only needs programming. The Java SunSpots (Java Sunspot, http://www.sunspotworld.com) takes the latter approach: in a small module a number of sensors (movement, temperature, light intensity) has been provided together with a controller, a small battery and a radio circuit. Through a PC, one module can act as gateway to the internet for the other modules. Although many examples of single value devices can be built using this hardware, it might be impossible to design a single piece of hardware which will not at a certain point severely limit the design space.

For the first three functions (sensing, actuation, control) numerous dedicated kits, modules and sets, among which Matthews et al. (2003), are available. Arduino (http://www.arduino.cc/) boards with ‘shields’, Parallax (http://www.parallax.com/) modules – all are used in many physical computing (O’Sullivan and Igoe, 2004) or interaction design courses for designing ‘smart systems’. These kits are widely supported with documentation and examples and a large user community. In all cases a little – or at least some – experience with electronics is necessary to make systems work, see for example Igoe (2011).

Also complete toolkits exist which incorporate power (batteries) and connectivity for experimenting with wireless sensor networks and internet connectivity. Jeelabs (http://www.jeelabs.com) designs and provides a range of Arduino-based wireless sensor nodes and components for a base station which can connect them to the internet.

Some modules for powering and connectivity also exist, but since the sets are mainly aimed at designing prototypes, mostly ‘ad-hoc’ solutions can be found. There are power modules that use batteries or LiPo cells, which work in a lab experiment but are not suitable for using a product for years in a ‘normal’ operation cycle. Modules for wireless communication and internet connectivity also exist, such as Arduino’s (http://www.arduino.cc/) ethernet shield, but these require extensive knowledge about network configuration (since every network connection has different levels of encryption, addresses, etc.).

Through a number of experimental setups we try to establish a 'toolkit' which contains all necessary components for developers to design and construct single value devices which can be used in real life application. A user test of a background device which cannot be tested long enough keeps suffering from the novelty effect, instead of establishing a meaningful relationship between product and user. Hence for developing this toolkit the focus lies on two points which influence or hamper the practical implementation the most: power and connectivity.

In our opinion stable solutions for both power and connectivity are necessary in order to give single value devices a place in the world beyond the laboratory. 'Maintenance-free-ness' is one of the most important qualities for a device in order for it to function in the background. Power consumption (replacing or recharging batteries) and (lack of) connectivity are obstructions for single value devices in becoming 'calm' or 'background' technology.

4.2.4 Power

Most available options for powering the components in a kit consist of power supplies which connect to the mains, batteries or rechargeable batteries which can be charged using an external charger – or more recently – USB ports.

Using a rechargeable battery, depending on the used actuator and connectivity gives a device an operation cycle comparable to a mobile phone. This means that the device has to be tended to (attended) once a week up to once a day. This might be undesirable for a device that has been designed as 'background technology'. For most of the static objects power supply is not an issue, a wall socket will do. For small portable devices like the jewelry of Wallace (2004) or the blocks by Cottam (2009) regular recharging might interrupt the desired operation cycle. The level of power consumption is different for devices that have only a sensing function; most of the actuators require substantial power (comparable to a mobile phone).

When designing mobile applications, reduction of energy consumption is important. Most of the existing kits and sets are not tailored to energy efficiency.

Most of the available embedded controllers such as the Arduino offer options in software to reduce power consumption with tools such as sleep modes and watchdog timers. The hardware itself however is not directly suitable for running on batteries in an efficient manner. Also the capability to switch on or off the used modules, sensors and network connectivity is necessary to create a power efficient system. Although these steps can be taken with a standard controller, they require some in-depth knowledge of controller hardware and electronic design-making it a hurdle for general designers.

Summarising, the toolkit solutions for designing single value devices regarding power should include:

- a combination of efficient circuits for charging batteries and regulating battery power, also allowing external charge sources (motion, solar panel)
- software libraries using watchdog-timers and other power-saving features making it easy to make a power-efficient design

- preferably external sensors and modules that can be switched into a ‘power save’ mode or be turned off completely by central control
- all ‘normal’ options for operating on a standard wall-socket or power supply.

4.2.5 Connectivity

For (wireless) connection numerous options exist. Most of the wireless connections require a form of subscriber service, such as the subscription for access to a radio data network or (more common) the SIM card necessary for accessing the GSM network. One immediate problem with using a form of connection that requires a subscription is that this subscription requires (monetary) attention in order to keep functioning – which again withdraws an object from the background. Internet, however, is becoming ubiquitous, and in most households and working environments (at least in the western world) the same type of connection has been available for a number of years. Continuity of the connection is important for a device that is supposed to have as little focus on configuration as possible.

4.2.6 Internet

One of the most common used technologies for making (worldwide) connections is the internet. Connecting a device to the internet and making a device accessible trough the internet are typical examples of recurring problems when designing single value devices. The solutions are often very specific due to varying conditions in local networks, as highlighted in the following cases:

- *Addressing:* In most networks, addresses are assigned using a dynamic host configuration protocol (DHCP) service. In some networks however addresses have to be assigned manually. Some networks require registering the MAC addresses of devices first at a router before they can access the net.
- *Accessibility:* Devices on for example our university network get addresses by which they can be accessed publicly. In most private households however routers assign local addresses to devices and employ network address translation (NAT) to enable restricted communication with the public internet. To make a local device accessible publicly, manual interventions such as port forwarding are required.
- *Name resolution:* While local name resolution using multicast DNS (mDNS) typically works on ethernet networks, mDNS packets are usually not forwarded to wireless networks due to the bandwidth usage of multicast communication in crowded wireless networks.

These are issues many potential developers and certainly most of the end users do not want to spent time on. While networking may work as desired during prototyping in a lab-environment, the moment the device is to be moved to a different network, be it for a demonstration, a user evaluation or the deployment to an end user, the previously addressed problems will come to effect. Workarounds can be conceived for most of these problems to make extensive user intervention a last resort instead of a default: For example traversal using relays around NAT (TURN) (Rosenberg et al., 2009) techniques can be used to make devices publicly accessible. A web service that allows devices to register their local address under a unique identifier can be used to enable name resolution through a redirecting website. Various peer-to-peer software manages to make connections for file- and data transfer outside the normal server-client model. VOIP software like Skype manages to make peer to peer connections using a combined strategy of a central 'phone book' server and a technique called 'UDP hole punching' (Wikipedia on UDP Hole Punching, http://en.wikipedia.org/wiki/UDP_hole_punching).

However, even such workarounds may not succeed in all cases. A very strict firewall might render them useless, requiring yet another workaround (or even user intervention). To relieve users, implementations of these workarounds should be part of the toolbox, including a programmed strategy that chooses the appropriate actions degrading from the most automatic/efficient to the most manual/inefficient. The result would be, figuratively speaking, a 'hacker in a box'.

Other issues regarding internet connectivity however are not simply solved by software workarounds. This is the case when network facilities simply do not exist or cannot be used as expected. In some locations there might be no ethernet ports nearby or there is only a Wireless LAN that is highly secured. Besides using GSM or other data network, the use of a smart gateway, as proposed in Guinard et al. (2011), might be a conceivable solution. A smart gateway is a dedicated device that on one end uses a communication method to communicate with single value devices (short range radio, Infrared, wire, etc.) and on the other end uses an ethernet interface to communicate with the IP network, forwarding messages in both directions.

Summarising: the toolkit should include a device or system combining the 'hacker in a box' and smart gateway functionality. A prototype of this system is being developed which may result in an all-in-one, plug'n'play solution for the connectivity problem both during design and deployment of single value devices. Furthermore, such a device could also take over other functionality, such as updates of applications and services, the device coupling and data aggregation.

The current state of the art offers much in easy programmable devices, simple to connect sensors and plug-and-play modules. Networking and power supply are however the two main obstacles to tackle in a toolbox for developing single value devices.

4.3 Design issue: generic vs. individual design

A challenge in the design of single value devices is how to design objects which users attach meaning to. The tension resulting here lies between design for large scale production versus the individuality of single value devices.

Single value devices only 'work' if the meaning of the physical object corresponds to the meaning of the information delivered. To one part, for each sort of information the perception becomes easier if it is displayed in an object that connects to this information, called ambient counterpart in Gellersen et al. (1999). To another part, the emotional content and the imagination beyond functionality may increase our overall receptivity of an object.

The meaning of an object is composed of a range of different aspects. First, there is an emotional meaning of objects, which is highly personal, as memories to people and places. Aesthetics emphasis, as discussed by Pousman and Stasko (2006) as one of their design patterns, is another very personal source of emotion and meaning attached to an object. Finally, we have expressions of cultural contexts, ranging from archetypes to subculture icons, where objects may carry a symbolical or metaphorical content.

Attaching meaning to an object is an action of a person (Csikszentmihalyi and Rochberg-Halton, 1981), it is not an inherent property of an object. Different people can attach different meanings to the same object. The basic question here is, how to design an object that stimulates users to attach meaning to it? In our examples we find two extreme approaches. The necklaces in Seymour (2008) are designed personally for two people, taking their shared memories into account: e.g., elements from illustrations of fairy tales read together. The other extreme is to design a very neutral object and give space for projecting meaning to it. The white stones (Tollmar et al., 2000) and Coconatch (http://www.coconatch.com) have a tenuous design allowing for different connotations.

Summarising, there are the choices of either designing a new, dedicated object as carrier for information, or taking an existing object with the emotional connotation and meaning already associated to it.

Another choice is to equip or 'instrument' *existing* personal objects, that already carry emotional meaning for a user, with technology, as done with the tangible bits (Ishii and Ullmer, 1997). A very invasive strategy (i.e., the object itself is changed) is followed with the internet enabled furby (Dertien, 2009): after treatment it cannot be used anymore as a normal Furby. A more restrained approach is that of the Lumitouch photo frame (Chang et al., 2001) carrying a personal photo. To generalise the approach of non-invasive technology added to existing objects (i.e., a technology that leaves the objects completely unchanged), we suggest to develop light-giving pedestals or small display cases in which one can put highly valued personal objects.

In Ishii and Ullmer (1997), it is suggested to take walls, ceilings, and surfaces also as possible objects to carry information. This solution contains elements of both approaches: as a new object, not connected to the content of the information in itself, it is a very neutral object. On the other hand, walls, ceilings and surfaces exist already and are equipped with information.

4.4 Design issue: customisability

4.4.1 Configurability

Configurability is the answer of consumer electronics to catering for individual needs while, at the same time, concentrating on cheap mass production. Collective experiences with configuration of video players taught us that elaborate configuration processes do not increase ease of use, but rather decrease the number of potential users. The requirements of simplicity in usability for single value devices imply that other solutions have to be found.

As discussed in Section 4.1 some applications that present informations tailored to the needs of the end user require also some level of configuration. From this point of view, single value devices need to be extensively configurable. The question therefore is, how to design for the variety of individual needs and preferences, with respect to configuration. The solution we suggest is, that there must be a variety of single value devices. Common to all of these must be that they do not require configuration for network connection or pairing, as elaborated in Section 4.2.

4.4.2 Apps and service models

Closely related to the configuration question is the need for applications. When wanting to configure functionality, i.e., change functionality, there is need for programmable services. Examples are products that are connected to a webserver providing a number of applications to choose from, e.g., Nabaztag (http://www.nabaztag.com) and Ambient orb (http://www.ambientdevices.com/cat/orb/MANAmbientOrb3-23-03.pdf). Additionally, if the set of applications is fixed, over time the single value device designed for changing applications will get boring. Solutions here are either, that there will be new applications made available from time to time, or, that there is a possibility for people who are capable of designing an application to do that.

Additionally, many single value devices will depend on content that is provided by third parties on the internet, like for weather information. Protocols of local networks may change or internet protocols get updates. All these aspects together imply that single value devices are products that have to come with a service model allowing to update and keep them alive.

4.4.3 Variety of devices

Next to different configuration needs and abilities, there are other needs for a range of single value devices. Perception is individual. Some people are more receptive for light, others for sound. What one person experiences as calm, e.g., the slow change of colours or the sound of rain, may be annoying for someone else. Colour blind people will not appreciate light indicators where they cannot distinguish the colours. Deaf people should not have sound alarms. Tracking by GSM can be experienced as surveillance, crossing the border of privacy, or, contrary, an expansion of the range of acting safely, and getting help, if necessary.

5 Conclusions

Single value devices have a potential that is not yet realised. They can integrate into daily life in an unobtrusive and aesthetic way. The variety of applications is huge, from motivating to live healthier to reminding of everyday duties, from telepresence to simple playful communicators. But still, very few commercial products exist. Most of the examples available are prototypes exploring conceptual design choices. Aiming at commercial products a more integral view on single value devices is necessary, to which the work presented contributes.

We investigated the design choices by, first, exploring existing examples in a survey, and, in a second step, distilling the characteristics in a taxonomy of single value devices. The taxonomy in itself is already useful to identify unexplored areas in the design space. Furthermore, we contribute a critical discussion about how to design objects with emotional connotation, which is certainly underlying in many publications and prototype developments on single value devices. Further discussions addressed toolboxes for hardware and connectivity solutions, customisability, and the service concept that inherently gets introduced with single value devices. Our future efforts will aim at a more mature version of the toolbox and the smart gateway solutions that we propose, and at experimenting with a variety of projects in which we prove our platform and explore the possibilities of applications.

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