Lucolla and Lessons for the Design of Growing Systems

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Abstract
We present the design of Lucolla, a light object and controller for intelligent lighting environments. Lucolla is a product that allows us to investigate how to design for a future where products are networked and interoperable, and where the designer of products is faced with a design challenge that is of an open-ended nature. Through our design activity we investigate three challenges that we evaluate and reflect on with the design of Lucolla. We show how products can deal with dynamic system topologies and how user preferences can be captured in interaction with systems.

Author Keywords
Growing systems; intelligent environments; user involvement; contextual preferences.

ACM Classification Keywords
H.5.m. Miscellaneous.

General Terms
Human Factors; Design

Introduction
This paper presents the design of Lucolla, a tangible light controller that is designed to operate in a networked light environment. Lucolla is envisioned as

part of a ‘Growing System’; a vision that we shall introduce. Lucolla uses tangible interaction to allow people to interact with their lighting system. Furthermore, it leverages to activities and behavior of people to develop intelligent behavior of its own over time.

System Intelligence

Intelligent products and systems are considered the next step in our technological advance. Ever since Weiser published his work on Ubiquitous Computing [11] many research groups have worked on systems that fade into the background, and present their support at opportune moments. Aarts and Marzano present five key characteristics for systems to become (ambient) intelligent; devices shall be embedded, context-aware, personalized, adaptive and anticipatory [5].

Although concepts for these types of systems have been around for almost two decades in academic research practices, large-scale adoption of such systems by the consumer market has yet to take place. Few intelligent products have found their way onto the consumer market. An example of a service that can be considered intelligence using the characteristics of Ambient Intelligence is the *Google Now* service [4]. Google Now is a digital assistant that pro-actively presents you with updates, suggestions and information during the day. Google Now uses information in your agenda, e-mail, (social media) profiles, Internet activity, combines this with your whereabouts and presents you ‘cards’ with information that might be relevant for you at that given time and place. This service is personalized, adaptive, anticipatory and aware of its context, yet is fixed to a virtual environment.

Growing Systems

One of the issues of many of the proposed intelligent concepts is their disruptive nature; one essentially has to abandon all existing technological infrastructure and rebuild the intelligent system as a whole. We believe in a more gradual approach towards the integration of intelligent systems into our daily lives; design for growing systems [1] as described by Frens. We believe products should be designed such that they can interoperate with other products. If two products are combined, new functionalities may emerge that were not present with the original products. An example that (perhaps outdated) exemplifies this process is that a scanner combined with a printer can have the functionality of a copier. This copier combined with a network connection acts as a fax. The resulting behavior of the system of products is more than simply the sum of all products. The most important benefit of such an approach is that people compile a system over time. The type of systems we refer to can also be created ad-hoc; as products enter or leave the system, functions are combined to create new functionalities. The result is a dynamic topology of products that collaborate in a given context to provide specific functionalities.

Such an approach significantly impacts the design process. The designer needs to take into account that his product may be combined with products of others. The designer thus needs to open up the functionality of his products to other products. This approach is already visible for many Web 2.0 and social media applications, where developers provide others with access to their system via Application Programming Interfaces (APIs) (e.g. [1],[5],[11]). Also in the research field there are large projects that investigate interoperability between different products and systems, for example the SOFIA project [10]. We believe that also physical products can benefit from such an open-ended structure.

However, such an open-ended system faces the designer with a new challenge. The designer is limited by his perspective on the design challenge at a given point in time: as described systems are formed by transient elements; i.e., people come and go, technologies change and the use of the system changes. The result is a difficult paradox: design is about defining functionalities of a product, yet it becomes impossible to know up-front all the possible states in which a system can be, or in which states the system should be to satisfy user preferences as the designer does not know which products his product may need to interoperate with. With the design of Lucolla we show an approach on how a designer can deal with this open-ended challenge for the design of products.

User Involvement

Fundamental in our design process is the idea that users should be involved in order to make products behave intelligent. We believe that it is not the designer, but the user that should define the behavior of the product or system. After all, the interaction with a product in context is what provides meaning to the user.

One possible way to deal with this open-endedness is to involve the user in configuring the system [] and making it meaningful to him. For example, end-user programmable products like the Logitech Harmony One [3] remote allow the user to control any device with an infrared receiver. The configuration of buttons and their corresponding actions has to be defined by the user in a software environment. The remote can be programmed by the user to control specific devices for a specific activity.

With Lucolla we present a similar, yet slightly different approach towards involving users in ‘educating’ their intelligent systems. As a starting point we take it that the behavior of people is often a reflection of their desires or preferences. For example if a user closes the blinds in his office, he is not satisfied with the current lighting conditions at that moment. While for the design of many intelligent systems, the designer attempts to create rules and inferences to design system behavior. We believe that if products could capture this relational understanding between people and their environment, a system *can develop* intelligence. Additionally, we want rules for system intelligence to be contextually dependent. This allows users to make system intelligence contextually meaningful; to relate to our previous example, I might want to close the blinds when I’m working in my office as it create glare on my screen, but at home I want to enjoy the sunlight and leave the blinds open.

This section described the background perspectives for our design activity. We presented the vision of growing systems and the new challenges this poses for the designer. We proposed user involvement as a mechanism to deal with the open-endedness of the design challenge. In the following section we introduce the specific context of our design and we present the design of Lucolla.

Lucolla, a Light Controller

Our work is situated in the domain of adaptive and intelligent lighting environments. In on-going research we are developing intelligent lighting systems and applications. This has led to the development of two lighting installations in our working environments that are used as Living Labs. Living Labs are used to design and evaluate innovative concepts in realistic contexts. The two contexts are introduced in the following sections.

The aim of the project was to design a controller that would allow users to control lighting conditions in a tangible and meaningful way in the two contexts. Importantly, as the lighting setups are also research prototypes and subject to change, the controller needs to be able to deal with such changes in the lighting setup. As such, the two contexts resemble a dynamic system topology. Additionally, the controller needs to be able to capture the user preferences for the different contexts and for different activities they perform. The controller should provide a mechanism for the system to learn the user preferences in interaction.

Contextual Setting

As before mentioned two lighting setups are currently installed in our working environment. The first lighting setup is installed in a meeting room for up to 8 people. A ceiling, consisting of custom designed light tiles is installed above a table (180x180cm). Each tile is equipped with three 3-watt warm white and cool white light emitting diodes and a wireless node. Each of the tiles can individually be controlled via a wireless network. In addition, each tile can be equipped with sensors and can be programmed to respond to relevant sensor data. Figure 1 shows the meeting environment with the meeting table and ceiling installation above it.

Figure 1: Example of the open-plan office with individual light sources Light sources can be controlled individually by intensity and colour temperature.

The second installation is placed in a 'break out area' [9] (shown in Figure 2). This is an area where people can retreat to work individually or in small groups. This context is equipped with colored wall-washers (RGB) and decorative lighting. All light sources can be controlled individually to provide a wide range of lighting conditions and atmospheres.

Both installations use the same wireless nodes to control the lighting equipment. The nodes all have an XBee transceiver, making it possible to transmit one-to-one and one-to-many messages. The shared technology makes both installations interoperable.

Figure 2: Impression of the breakout area. Figure shows a retreat area where people can relax or perform individual work. Light sources can be controlled individually by colour and intensity.

The Design of Lucolla

Lucolla is a combination of a light source and a light controller. There are several qualities embedded in the design of Lucolla that originate from the design challenges outlined in the introduction section. In this section we elaborate on these qualities and explain how people can interact with Lucolla.

PORTABILITY AND FLEXIBILITY

A characteristic of the prototype is *portability*. Lucolla is 100 mm wide, 510 mm long (fully stretched) and 25 mm thick. This size allows users to take the object to different spaces and contexts. Furthermore it has a flexible form factor; it consists of 11 elements connected through hinges. Lucolla can maintain its form by servomotors attached to the hinges.

Figure 3: The Lucolla Prototype.

As Lucolla can also provide light itself, users can use the object as a portable light source. As such it can be used for different activities in different contexts. E.g. Lucolla standing erect with light directed downwards can be used as a desk-lamp in the office or for reading the newspaper at home. In another way when it is placed on its side it can be used as decorative lighting. People can use Lucolla for different purposes as the flexible shape provides several degrees of freedom.

As Lucolla uses servomotors to maintain its shape, the user can’t manipulate the shape directly. Instead we have chosen to use stroking gestures to change the shape. The backsides of the elements all contain a capacitive touch sensor. Lucolla as a whole thus forms a touch sensitive slider. The direction and speed with which the user strokes Lucolla determines how it transforms. The speed of the stroking gesture is mapped to the amount of transformation. The direction of the gesture is mapped to the direction of transformation. Figure 4 shows examples of how one can alter the shape of Lucolla using theses gestures.

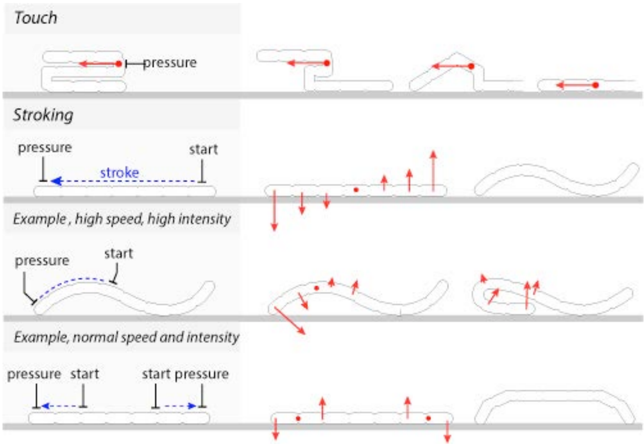

Figure 4: Manipulating the shape of Lucolla using different strokes.

Contextual Preferences

The prototype also comprises a three-axis accelerometer, a color sensor and a wireless node (similar to the ones that are used in the other installations). This allows Lucolla to sense its orientation (in x-, y-, z-rotation) using the accelerometer. With the color sensor, we measure the color of the surface the object is placed. The wireless node allows communication between Lucolla and its surroundings. This node is used to detect which other nodes are present and using measures of the signal strength of received messages, it can approximate the distance to surrounding nodes. Combining these data allow Lucolla to distinguish different locations. A specific location is then constituted of the orientation of the object, the distance to other nodes in the environment, and the color of the surface it is placed on.

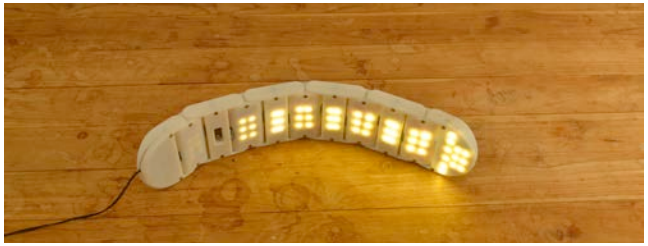

Figure 5: Lucolla in different shapes and orientations

This information is captured to provide Lucolla with the ability to recognize different contextual settings. E.g. if Lucolla is taken to the meeting room (described before), and placed on the table, a combination of orientation, surface color and surrounding nodes emerges. This combination of data is unique, and can linked to lighting preferences. Consider the following as an example: if a similar table would be placed in the breakout area, and the object is placed on this table, the orientation and surface color sensed would be similar, yet the combination of surroundings nodes is different. It is thus recognized as a new location.

Controlling Light

As explained, Lucolla is a light source in itself as well as controller for other light sources. In this section we first explain how the user can manipulate the light emitted by Lucolla. Secondly, we explain how its shape controls other light sources in the environment.

The backside of each element is equipped with capacitive touch sensors. When the user touches two elements simultaneously, the elements in-between these elements will turn on and form a body of light. By touching a single element the user moves the body of light. This allows the user to manipulate the size and the location of the light body.

We have also designed a relation between the physical shape of Lucolla and the light qualities of the surrounding light sources. These light settings are deduced from three parameters of Lucolla's shape (see Figure 6):

1. A parameter that we call 'focus' is determined by the curvature of the shape as a whole. The focus parameter determines what type of surrounding light sources 'listen' to our object; diffuse light sources (e.g. wall-washers in the break out area) or focused and directed light sources (e.g. ceiling tiles in the meeting room) or a combination.

2. The light colour of surrounding light sources is determined by the 'sharpness' of Lucolla. A large variance in the angles between elements constitutes a highly angular shape and results in a cooler light colour (temperature). Smaller variance of angles results in a warmer light colour (temperature).

3. The light intensity is determined by the 'degree of opening' of Lucolla. A closed shape indicates a low light intensity, while an open shape results in a higher light intensity of the light sources in the environment.

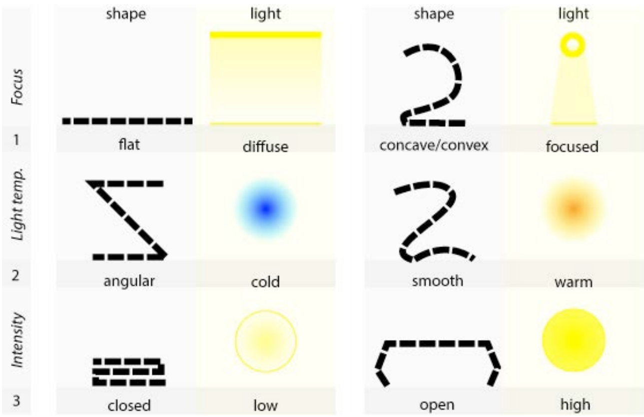

Figure 6: The different parameters deduced from the shape of Lucolla and their resulting light qualities of surrounding light sources.

The various functionalities of Lucolla presented in this section allow users to manipulate the shape, light emitted by Lucolla, and the surrounding light sources using several degrees of freedom. Lucolla stores the light settings created by the user and links them to different contexts and activities. Whenever a user returns to a known context or activity, Lucolla restores the previous settings. In this way, users can create meaningful light settings for different activities in different contexts.

Use-case scenario

In this section we outline a use-case scenario that shows how Lucolla is used and develops contextualized light preferences over time.

Contextualizing Preferences

Our fictive user George visits the meeting room for the first time with his Lucolla. He places it on the table and explores how to manipulate the shape and light of Lucolla and its effect on the surrounding light sources. In the end George ends up with a shape that provides downward lighting with a high light intensity. For now he uses Lucolla as his main source of light directed at his work area. The other light sources serve a purpose as peripheral lighting. Lucolla stores a preference for this specific context and the light settings created. George continues to work in the room. Later that day he has an informal meeting with two colleagues and decides to go to the breakout area. As he has some experience with manipulating the shape of Lucolla, he manages to create an informal light atmosphere, with rather bright, yet warm white light. The light emitted by the object is in this case less relevant to George and his colleagues. Again the light settings are stored in a new preference and related to the orientation and context of Lucolla.

Overwriting Preferences

A week later George returns to the breakout area, yet this time for a more formal presentation to external clients. He restores the informal light settings by placing Lucolla in the same location on the same surface as one week earlier. As he has a week of experience with manipulating Lucolla he is able to rather quickly create a more formal light atmosphere with cool bright light. As soon as he starts his presentation, George closes Lucolla with a single gesture and the light dims. The earlier preferences are overwritten with the new light settings, as the object is in the same context, on the same surface in the same orientation.

Adding Preferences

After a successful presentation, George goes to the meeting environment to update his colleagues. He places Lucolla on the table and his individual work preferences are restored. However, George does not want to override these settings, but wants to have different light settings. He rotates Lucolla on its side and adjusts its shape to create the desired light settings. The context is recognized through the other wireless nodes, but there is no preference for the given orientation. A new preference is created for this context with the current orientation and the current light settings. In a similar way George could have placed Lucolla on a different surface to create a new preference.

Conclusions and reflections

With the design of Lucolla we presented a light controller that can operate in various intelligent lighting environments. We have built a prototype for Lucolla and integrated it into our existing installations. We have not yet performed any formal evaluation. The insights presented in this section are a result of the design activity combined with designerly critique from colleagues.

In the introduction section we have presented three design challenges for the design of growing systems and for the development of system intelligence. This section addresses these challenges and the insights gained from our design activity.

First, we want to show if a single controller can be used to control light settings in different contexts. By parameterizing the physical shape of Lucolla and relating this to lighting qualities we have been able to achieve this. This makes it possible to operate Lucolla in an unknown lighting environment without explicit configuration, with the constraint that the lighting objects in this environment are susceptible to external commands of the type Lucolla provides (e.g. it uses commands such as 'set light intensity to…' or 'change light color to…'). Commands that are unrecognized, or that the device is unable to execute, can be ignored (e.g. a light source that is unable to change its light color should not respond to a 'change light color' command). We are offloading the intelligence and decision making process from a centralized perspective (one node telling all the others what to do) to a decentralized perspective (each node deciding for itself what to act upon). For the future we want to explore what actions individual light sources could/should take when they encounter commands that are unknown to them.

Another advantage of linking the lighting qualities to the physical shape is that Lucolla has become a tangible representation of the system's state. We have for example experienced that dimming the light for the environment, as a whole has become a comprehensible action. By transforming the shape of Lucolla to a more closed shape, the light dims, and vice versa. The interaction of closing or opening the object's shape has become a meaningful action of adjust the light intensity of the system.

Secondly, with Lucolla we have shown that we can deal with dynamic system topologies and that we can deduce information from this. New light sources that are added or removed can directly by controlled by Lucolla. There are some technical prerequisites for this, but we take it that these are present in every (networked) interoperable system. When the system is able to transmit messages between nodes, the system topology can become a valuable source of information. In this case we have taken the combination of wireless nodes in an environment as a variable to represent that environment. When the topology of nodes is highly dynamic (e.g. changing on a daily basis) this mechanism has its limitations. However, for lighting systems it is our experience that changes in system topology are not frequent.

Thirdly we have shown a mechanism to create preferences that are tailored to context and activity. By capturing the behavior of people in interaction, and relating this to context-dependent variables we are able to capture context dependent user preferences. We believe this mechanism of dealing with preferences is more likely to provide accurate responses to user behavior than general rules for the system. For the future we plan to integrate machine-learning algorithms to explore patterns in the users' lighting preferences [3]. Similarities between preferences could be used to suggest light conditions to users for new contexts but similar activities. This can provide Lucolla with anticipatory behavior over time; users will not have to set lighting conditions from scratch, but can build on earlier preferences.

This paper presented the design of Lucolla as a portable light object and light controller in the context of intelligent lighting environments. With the design we have shown how designers can deal with design challenges of an open-ended nature and can leverage the new possibilities to provide users with system behavior that is personalized, adaptive and contextually meaningful.

References

[1] Facebook Developers. http://developers.facebook.com/

[2] Frens, J.W., Overbeeke, C.J. Setting the Stage for the Design of Highly Interactive Systems. Proceedings of International Association of Societies of Design Research 2009 – IASDR’09 (2009), 1-10

[3] Gopalakrishna, A.K., Ozcelebi, T., Liotta, A., Lukkien, J.J. Exploiting machine learning for intelligent room lighting applications. Proceedings of Intelligent Systems (2012). 406 – 411.

[4] Google Now. http://www.google.com/landing/now/

[5] Holloway, S., Julien, C. The Case for End-User Programming of Ubiquitou Computing Environments. FoSER 2010 (2010), 167 – 171.

[6] LinkedIn Developers. http://developer.linkedin.com

[7] Logitech Harmony One Advanced Universal Remote. http://www.logitech.com/en-us/product/harmony-1100?crid=60.

[8] Marzano, S., Aarts. E. *The New Everyday – Views on Ambient Intelligence*. Uitgeverij 010 Publishers, 2003.

[9] Offermans, S., Kota Gopalakrishna, A., van Essen, H., Ozcelebi, T. Breakout 404 : A Smart Space Implementation for Lighting Services in the Office Domain. (2012) Proceedings of INSS 2012, 1-4.

[10] SOFIA project- Smart Objects For Intelligent Applications. http://www.sofia-project.eu/

[11] Twitter API. https://dev.twitter.com/

[12] Weiser, M. The computer for the 21st century. *Scientific American 265*, 3 (1991), 94-104.