Ambient Mapping

Practical Exploration of Supporting Rich Interactions in Growing Systems by Adapting Tangible Interaction to Surroundings

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ABSTRACT
This paper explores the concept of “Ambient Mapping” and its value as a mechanism for supporting Rich Interaction in growing systems. By exploring the concept itself and applying it to a multitude of theoretical scenarios, a practical experiment is defined and performed. The goal of this experiment is to illustrate the value of Ambient Mapping in the defined context. The paper expands on why a term like Ambient Mapping is missing from current literature, how to apply Ambient Mapping, what the value of Ambient Mapping is and how to further define it with practical applications.

Author Keywords
Tangible Interaction; Rich interaction; Growing Systems

ACM Classification Keywords
H.5.2. User Interfaces, Input devices and strategies.

INTRODUCTION
Beneath the surface of designing a tangible product lay many possible frameworks, references and ways of thinking [2,6,18,21]. Each of these provide their own unique insights and also carry their unique criticism. The frames of reference provided by the aforementioned tools aid the creation of a meaningful interaction between a computer and a user in a specific situation [3,20,21], which raises a common, shared challenge; what happens when the situation around the user and computer changes? Be it location, amount of users or temperature, this idea allows an investigation into defining what they mean for a tangible interaction framework. When a system grows there is a very tough, but important challenge for designers to face to accommodate a change without causing it.

This paper specifically focuses on the Rich Interaction framework by J. Frens [6,7,8,19]. Within this framework four approaches to growth have been defined that can accommodate a growing system. These “mechanisms” are defined as: Hybrid, Modular, Shape Changing and Service. [8] The current mechanisms focus mainly on changing the appearance of the interactible physically or digitally to convey the changing potential from from situation to situation, essentially creating a several modes or transitions of interaction for different situations.

While in the context of rich interaction it initially makes sense to have the available interaction change based on the situation, this paper explores specific contexts in which it makes more sense to change the relation between interaction and computer instead. By anticipating the expectations of a user in multiple scenarios with the same interaction possibilities, a very flexible, meaningful and manageable interaction could be realised. This link is referred to as mapping. Because this mapping changes dynamically based on the direct environment around it it is hereafter referred to as “Ambient Mapping”.

The main goal of this paper is to investigate whether the concept of Ambient Mapping is absent from the currently identified mechanisms of growth [8]. This is done by expanding on what Ambient Mapping means in the context of rich interaction and placing in several realistic theoretical scenarios. Knowledge gained from these thought experiments is consequently applied to a user test that is aimed to ultimately prove or disprove the importance of Ambient Mapping in design and the relevance of Ambient Mapping in the previously identified mechanisms of growth. Besides possibly coining a new approach to rich interaction in growing systems this paper also serves to provide insights into practically applying the theory to Industrial Design, by providing practical examples. Finally, this paper places rich interaction in growing systems in general into the real world, in an attempt to contribute to demonstrating its relevance in applied Interaction design.

CHALLENGE
The overarching subject of this research is “Connecting Rich Interaction In Growing Systems” or CRIGS. This means that there is a focus on breaking the single user paradigm that has defined Industrial Design. Instead of ‘one product - one user’ the ultimate goal is to create systems that grow with their surroundings without losing the richness in their interaction.

Growing Systems

Specifically in the emerging field of IoT [12,14,22,23] there is merit to researching CRIGS. As the boundaries of systems get harder to define and become less secluded to a single set of possible actions and reactions[23], it becomes more essential for designers to accommodate this change. This especially has implications for frameworks such as Rich Interaction as the current research has mainly been related to the quality of the interaction in a well defined scenario as opposed to the flexibility of the interaction. This very real-life emerging challenge is something that can and should be supported by research to keep a framework relevant in the future. Not only is this a big challenge, there is also a very interesting opportunity to bridging the gap between design and research by having research react on design and vice-versa.

At the time of writing, four mechanisms of growth have been identified and supported with examples to illustrate their value in a design process. These examples can be valuable in demonstrating the process of a designer or design student in a successful application of the defined theory,[8] making application far more evident.

Discoveries made in this paper follow a similar pattern, by providing support to interpretations with applied examples, a more direct link between research and design is targeted.

Positioning Mapping in Rich Interaction

The four defined mechanisms are; Hybrid, Modular, Shape Changing and Service. Following are some interpretations of these mechanisms that lead to and help to position the aforementioned ‘Ambient mapping’.

The hybrid approach characterises itself by using a (touch)screen-based approach to processing the rich aspects of an interaction. The Modular approach deals with richness by allowing multiple ‘modules’ to collectively shape the interaction. By rearranging and adding/removing parts of the system, growth is supported. The Shape Changing approach is more complex, in that it speaks to the imagination of many researchers but has also shown to be very difficult to effectively execute. As the name suggests, in this mechanism the physical shape of an interactible has to change, exposing suitable control possibilities for the situation. Finally, the service based approach changes an object in cycles. By offering a service to alter interaction possibilities, designers have the possibility to influence the way a product can be used by physically exchanging (parts of) a device.

These four methods have their own unique advantages and disadvantages, but also correspond in one notable way; the change in interaction has to be observed and processed by a user to serve its goal effectively. Effectively, this allows for a change in interaction that is behind the scenes and is not observed by the user. Contrary to showing the user there is an argument to be made to anticipating the way a user uses an object based on the context, capturing the intention of a user rather than trying to only entice an expected intention.

Let it be clear that this way of thinking is not immediately evident, as was observed countless times in preparation of this paper. Changing the effect an unaltered action has without notifying the user in any meaningful way seems to be, at the surface, in conflict with what Rich Interaction aims to achieve: involving cognitive, perceptual-motor and emotional skills in an interaction.[6]. When looking further into the relation between mapping and Rich Interaction however, an argument can be made for basing mapping on the context to be of great importance. The way a user perceives possible interactions is closely related to the surrounding situation[1,16] For example: take a light switch and bulb

Assuming the user is able to identify the relation between the button and the switch without trouble, the environment determines the expected outcome of changing the state of the switch or button. If the identified light is off, the user expects the switch to activate the light, if the light is on however, the user expects the switch to deactivate the light. In the described case, mapping changes without notifying the user. This change in mapping however, does not seem to alter the richness of interaction. Though the interaction does not seem an exceedingly meaningful one in both states, the liquidity of the mapping does not cause one to be less rich than the other.

Consequently, this suggests that defining and placing Ambient Mapping in CRIGS can be very valuable as it reveals a previously unexplored angle a way of applying the theory surrounding CRIGS. Instead of putting the cognitive load with the user, it is shifted to the system itself and, by extension, the designer.

EXPLORING AMBIENT INTERACTION

Definition and Borders

Ambient mapping approaches growth in a system in a unique way. By placing the dynamics in a that support a growing system in abstract space, not directly observable by the user[5,10,15], an opportunity arises to make systems more seamless to use [4]. When considering Ambient Mapping in a system, a designer is appealing to the most direct instincts a user has based on the surrounding situation. Obviously recognising these instincts upfront and incorporating them into a design is monumental task, but by considering multiple scenarios a product can already have an impact on the ease of use.

A proposition for the definition of Ambient Mapping then becomes: “Adjust the computer processed reaction a system has to user action, based on the immediate surrounding of the system and its user”. To support the pertinence of this description it will have to be applied to growing systems in the real world. As described in the introduction this is addressed by placing the proposed description of Ambient Mapping in a series of theoretical scenarios and applying conclusions drawn from this to a practical user test.

Scenarios

Described hereafter are three scenarios based on research and experience. While they do make assumptions about the

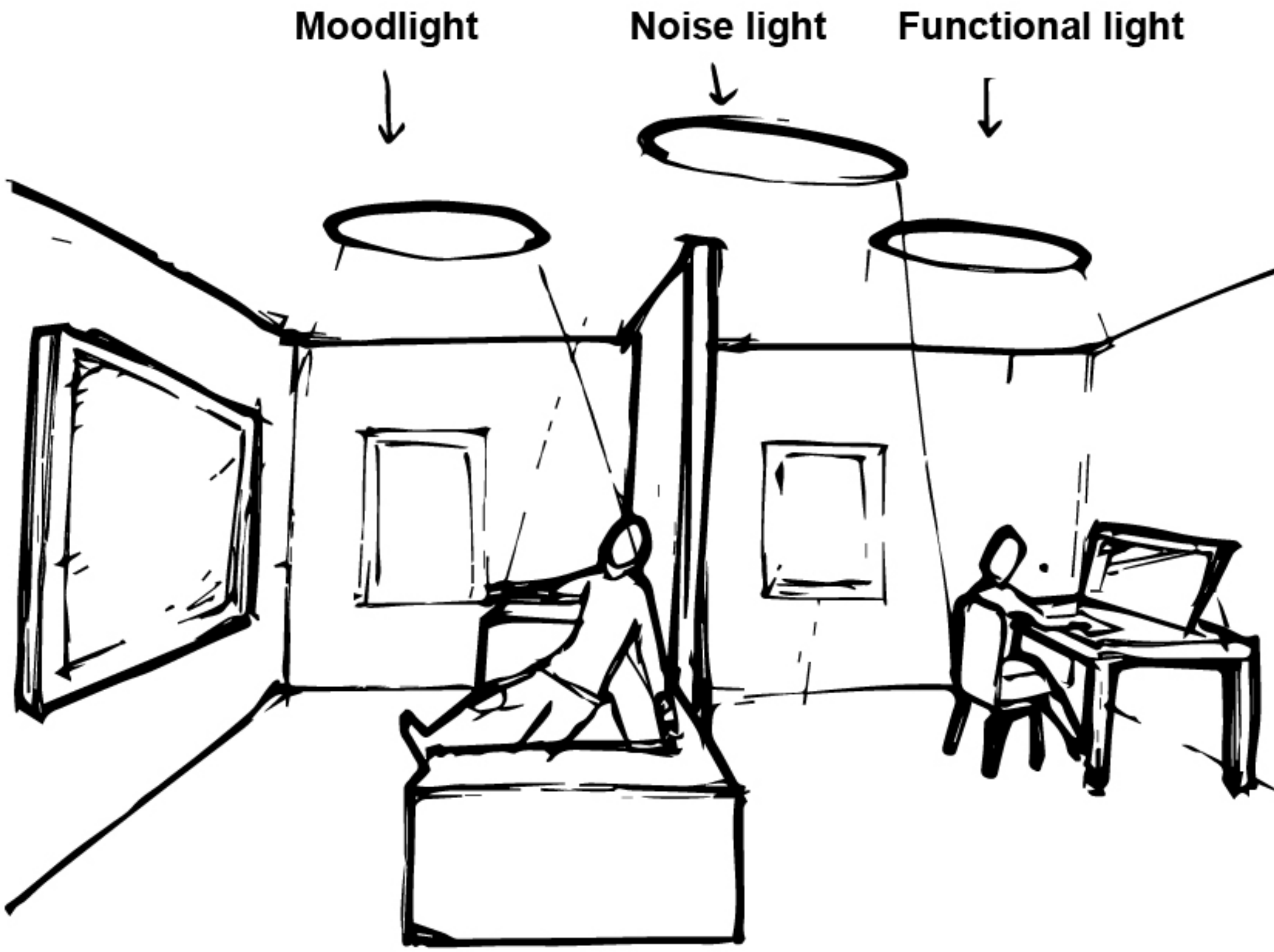

Figure , Scenario 1, lightning

functionality and value the systems would have in the real world, they serve mainly to provide a theoretical foundation of the advantages and disadvantages of Ambient Mapping. The practical user test can subsequently be based on this foundation in an attempt to provide a more conclusive data on the value of Ambient Mapping.

Lighting

This scenario involves a single room in which there is both entertainment space and a workplace. The entertainment space contains comfortable seating and a big TV with ambient lightning to increase immersion in movies [17]. The workplace on the other side of the room is simple and consists out of a desk with a computer and overhead lighting. Finally there is a light in the centre of the ceiling in between the two lights. All ceiling lights are capable of creating diffuse light in a wide variety of colours and temperatures. As more people start to utilise the space, a multitude of scenarios can take place.

In the event that only the entertainment side is occupied, the lighting in the ceiling of the entire room can react to the picture displayed in an attempt to immerse the viewer entirely. When only the workplace is in use, a neutral daylight-like light fills the room [13]. The daylight like light can gently take a warmer tint as night turns into day in order to facilitate sleep. Both systems are simply controlled by a conventional light switch.

Ambient Mapping manifests as follows: when both lightning systems are on, the Noise light emits a bright white glow. This light will certainly reduce the immersion caused by the moodlight, but will also aid in equalising the light across the room, approaching the workspace. While neither situation is ideal, the system uses available technologies to create an experience closest to what the user expects. The interaction a user has with the light switch remains unchanged in all situations, when the system notices however that there are multiple users with individual wishes, it alters the mapping to, in this case, create the best possible compromise.

Camera

This scenario assumes a camera that is rich and pleasant to use. The camera is used in a studio environment to photograph a subject. The subject is a scale model house and both interior and exterior shots of it are required to be made with the same camera. Because the lighting around the house barely changes there are two main settings on the camera, one for exterior and one for interior shots. This is a system that can constantly grow as more different shots with their own unique settings are added.

Setting 1 is for the exterior shots. To keep several shots consistent, the camera has to be set to exactly the same settings every time a similar shot is made to keep them consistent. Setting 1 has a relatively low aperture to make the scene seem more life size and a long shutter speed in order to still capture enough light. Setting 2 is for the interior shots. Again it is important to use consistent settings among all interior shots. The interior shots have a larger aperture to make up for lost light in the confined spaces.

For modern cameras it is relatively simple to detect the which focal length is best for the current situation. Therefore it should not be a problem for the camera to detect which of the two described states it is, allowing it to pre-apply the settings that were last used to take a picture in the same situation, which would be an ambient mapping according to the proposed description. In this way, a user can move between two or more situation and take consistent photos across the board without the risk of forgetting to change or misremember previously used settings.

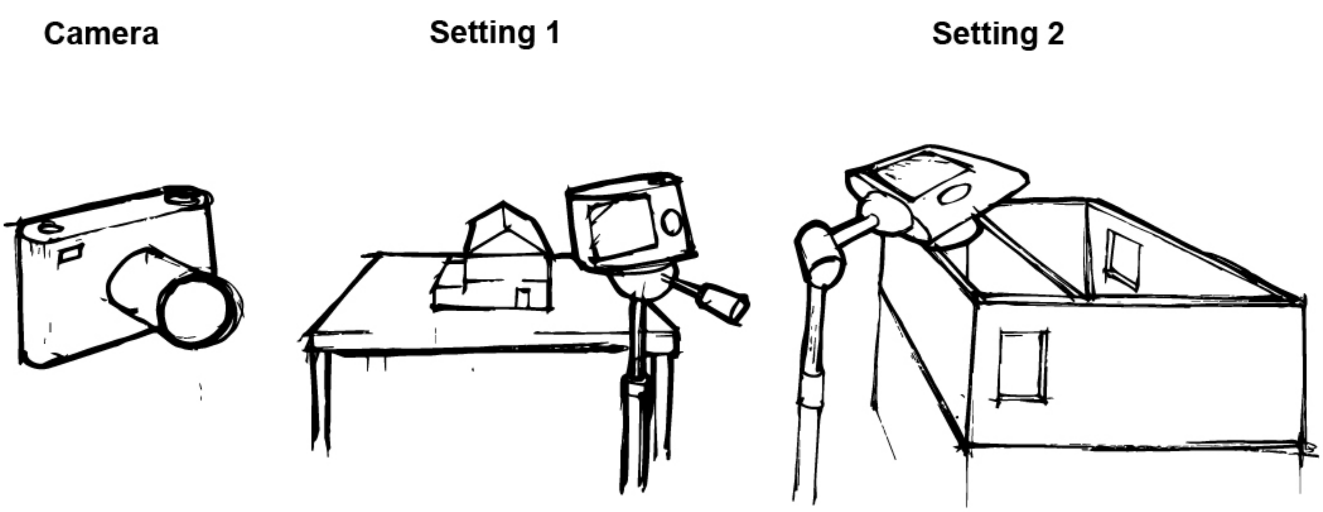

Figure 2, Scenario 2, camera

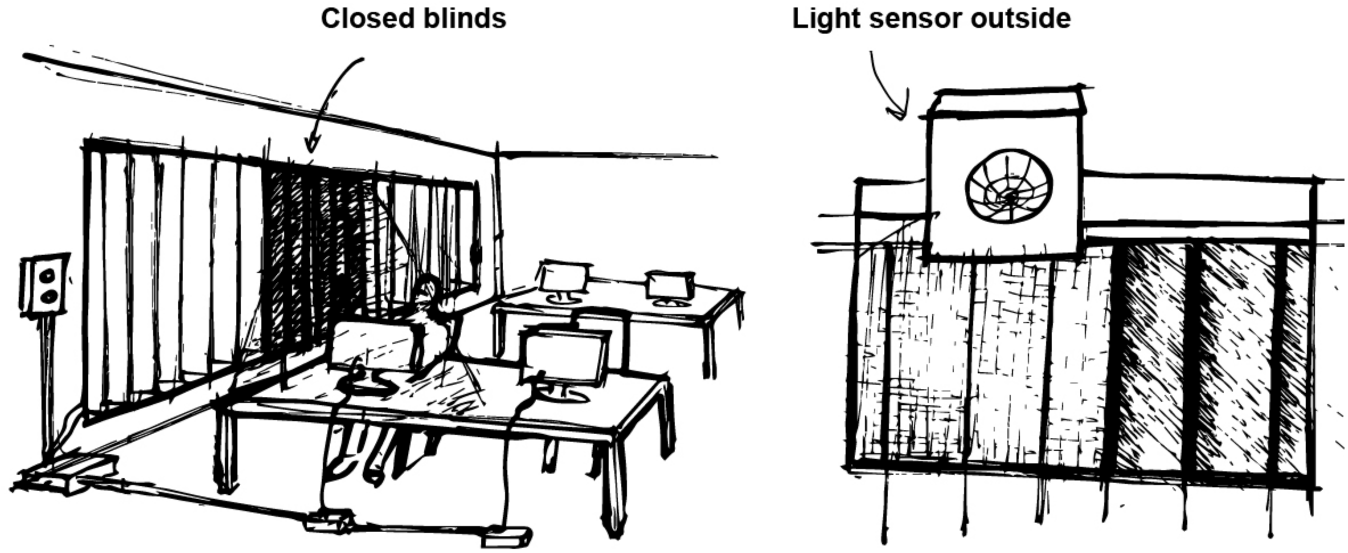

Figure 3, Scenario 3, shading

Shading

This scenario is positioned in an office that can accommodate multiple workers, not all workplaces are constantly occupied however. The office features a large window along the entire wall to allow as much sunlight in as possible during the day as this has potential to improve performance[13]. As the day progresses however, the sun also reaches positions in which it shines into the eyes of employees or creates glare on computer screens, which deteriorates the quality of the work environment.

To combat the problems the big window brings with it the employees are forced to either close all the blinds, wasting the sunlight. Or manually close individual blinds throughout the day, which is distracting and generally not something an employee wants to be focussing on during the workday.

With the aid of a light sensor on the outside of the building, a smart Ambient Mapping can be introduced . When a user notifies the system he wants the blinds to be closed as he normally would, the system simply measures at which workplaces there are computers turned on. By closing the blinds that interrupt direct sunlight into the eyes or onto the screens a minimal amount of blinds can be closed. In this way, employees can enjoy a light workplace, illuminated by diffuse sunlight all around them. The system measures the path of the sun during the day and opens and closes blind corresponding with the suns relation to the workplaces.

APPLICATION

In order to bring Ambient Mapping into the practical domain and distinguish insights gained from the scenarios previously described. A device was designed in an attempt to apply the theory to the real world, where it can be tested and further explored. The process which led to the design of this application will not be thoroughly expanded upon in this paper as it does not hold relevance to Ambient Mapping as such. Future plans for the device however are further elaborated, as they show how a system with Ambient Mapping in a product could potentially be developed.

Drawing Machine

The device is simple in function, but rich in possibilities. In essence it consists out of two types of devices, drawing nodes and a central drawing hub. For the actual test, two drawing nodes were devised, but as many as needed can be hooked up to the system. The central drawing hub processes input from the nodes and can either directly replicate movement from one of them, or process the input from multiple nodes and react to them.

The drawing nodes are small devices meant to be held in place by one hand and operated by the other. The user can grab the pen that is attached to it and move it to any place within the reach of the arms that the pen is attached to. The arms are connected to a set of potentiometers that allow the positions of them to be read.

The drawing hub is twice as large as the nodes and features arms that are also twice as long in order to provide it more reach, making user action more apparent and giving the users more range to explore. These arms hold a pen that draws on the surface the hub is placed on. When one drawing node is connected to it, a simple 1-to-1 direct mapping can take place. When two are connected, some kind of translation has to take place, this translation is completely programmable and will be the grounds for an Ambient Mapping.

Method

The device was tested on a group of 10 users, ranging in age from around 20 to 60 years old. The purpose of this test was to discover the value of a good Ambient Mapping to support a growing system. In order to simulate a growing system users was first asked to perform a simple task using one node with a direct mapping. After two users individually completed this task, they were asked to perform the same task collaboratively.

By comparing the accuracy of users individually and collaboratively the quality of the mapping compared to a direct mapping could be measured. The hypothesis is that users approach a system differently based on the situation around them. They expect a certain way of collaboration, which is something a designer can anticipate. Assuming that users do not first analyse the interaction thoroughly a mapping that correctly adapts to the situation around the system could help users understand and immediately use a system more effectively.

To be able to quantitatively measure the accuracy of a user that would be comparable in different situations a controlled repeatable test situation was created which had the same goal in both the individual and the collaborative situations. During the tests qualitative data was gathered by recording user remarks and interviewing them after completing both tests.

Experiment

The repeatable experiment that was devised consisted out of a maze that users had to navigate using the drawing machine. The maze was placed under the static hub, and users had to guide the pen through it while attempting to stay within the lines. The maze is very simple, finding the path from start to end was supposed to be effortless, and proved to be. The challenge for users was found in the actual guidance of the pen, the reaction of the hub to the nodes was not perfectly accurate. Navigating the maze perfectly was very challenging, but was achieved by test subjects.

Setup

To accommodate the collaborations, three different mappings were programmed into the system and cycled with each duo performing the test. The mappings combined the positions and movements of the two connected nodes each in their own unique way. The first mapping involved averaging the positions of the two connected nodes, placing the position of the drawing hub's pen exactly in between the two positions of the drawing nodes. The second mapping allowed each node to control one axis of the hub, only tracking one axis of each of the nodes. The Third and last mapping switched between the direct position of one of the nodes every 5 seconds, allowing each user to control the hub for 5 seconds at a time.

Each of the 10 participants performed the directly mapped individual test 1 time as well as the collaborative test, resulting in 10 individual results and 5 coupled results, 2 for mapping 1, 2 for mapping 2 and 1 for mapping 3. They weren't given information about the kind of mapping they would be asked to use when collaborating, with the goal to get the most pure and direct results from the test subjects. They were also asked not to share the mechanisms of the

Figure 4,The drawing machine. The drawing hub is in the centre, flanked by two drawing nodes.

device with others for the duration of this study, to prevent prior knowledge.

The three mappings provide the users with drastically different feedback, without changing any feedforward. If the users were to repeat the exact same motion from their individual test the result would be exactly the same no matter the mapping they would have gotten assigned. Each of the collaborative mappings would yield a perfect navigation if both users individually, simultaneously and accurately navigate the maze, any mutation is the quality of the navigation therefore is the result of the mapping.

Results

To grade the quality of navigation through the maze the amount of times users broke through the barriers were counted. Time was not considered a factor, as users were only encouraged to use the system in a way that made sense to them. Breaking trough a barrier and returning through the same barrier to a previous position was only counted as one mistake. If a user skipped part of the maze by going around it every 3 cm was counted as one mistake. After 15 mistakes the mistake count stops in order to not get out of hand in rare cases, this limit was only reached once.

To the right is a table with the processed data counting the number of mistakes the test subjects made and what mappings they were assigned. Like described earlier in this paper, mapping 1 is an average of the drawing nodes, mapping 2 allows both users to control one axis of the hub using their node, mapping 3 switches the control of the hub between the connected nodes every 5 seconds.

	Individual Mistakes	Collaborative Mistakes	Applied Mapping	Δ Mistakes
1	8	3	1	-5
2	7	3	1	-4
3	5	7	2	2
4	1	7	2	6
5	4	15	3	11
6	3	15	3	12
7	3	3	1	0
8	4	3	1	-1
9	9	9	2	0
10	3	9	2	6
Average	4,7	7,4		

Figure 5, Processed data of the amounts of mistakes made throughout the experiments.

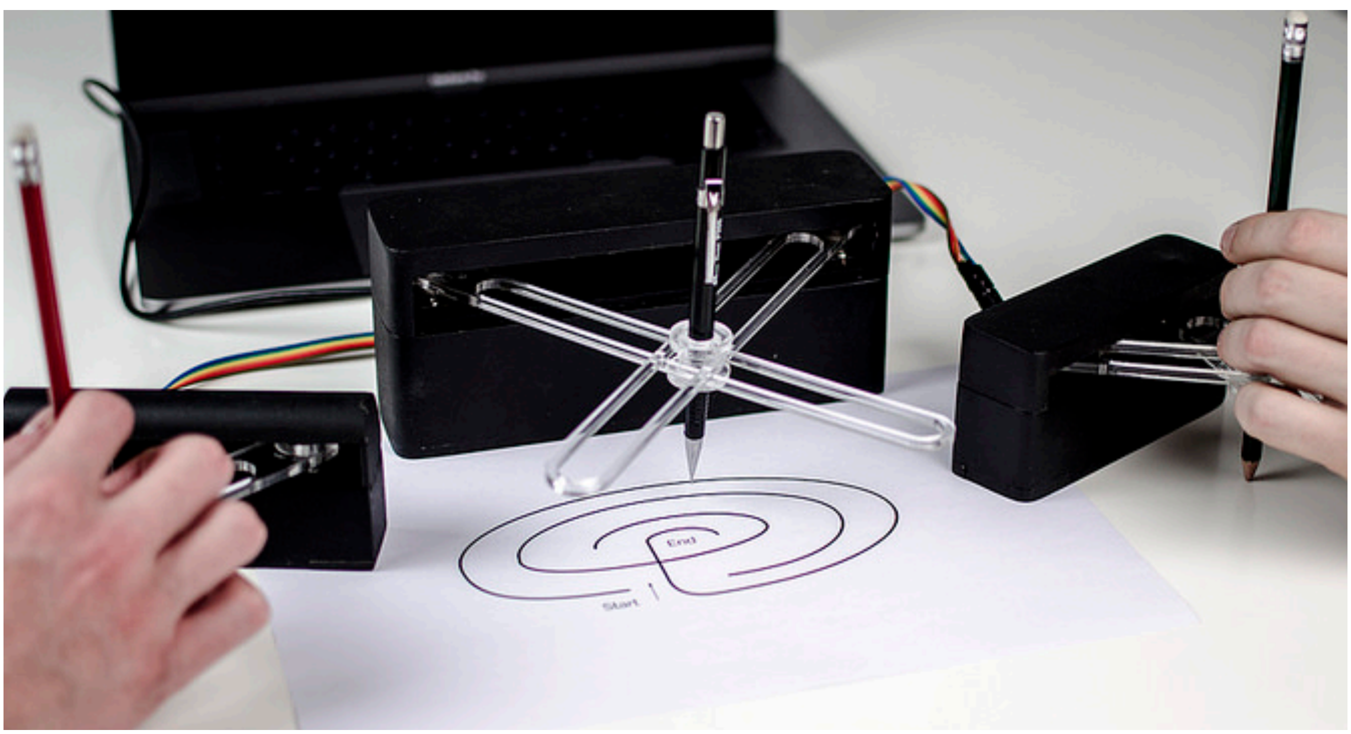

Figure 6,The drawing machine. The drawing hub is positioned over the maze used in the tests, two users are controlling the hub using their drawing nodes.

We can see that the average amount of mistakes made in the individual test was 4,7 and collaborating increased this to 7,4, a 57% increase. If we disregard the tests that reached the limit of 15 mistakes as outliers the average of Collaborative Mistakes becomes 5.5, a 17% increase.

Larger differences are revealed when splitting the mappings up in their own right, which can be observed in the following graph. This graph plots the average amounts of mistakes made individually against their performance

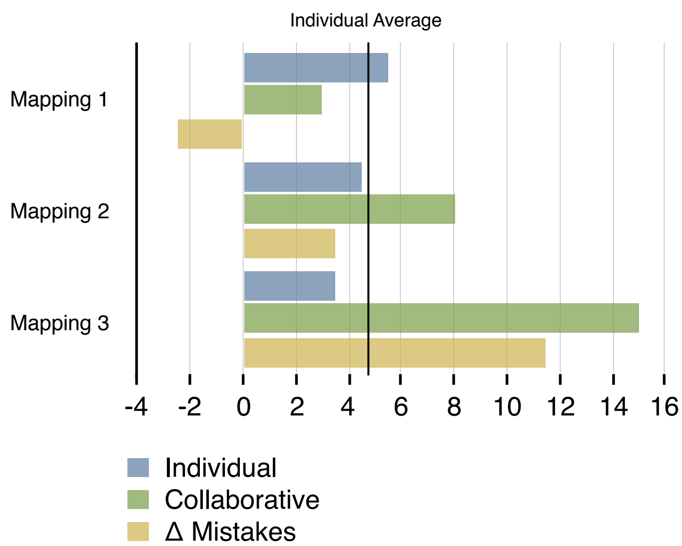

Figure 7, Graph showing the influence of collaborative mappings compared to the individual performance of users.

This makes it very apparent that the first mapping is by far the most effective of the three in the tested group. Mapping 1 resulted in a 46% decrease in mistakes, where Mapping 2 and Mapping 3 caused a 78% and 429% increase in mistakes.

Conclusion

Even though all of these mappings potentially yield the exact same result if both users navigated like they would have in their individual test simultaneously, they produce wildly different results. Most notably, Mapping 1 improving on individual results. This could potentially point to a "wisdom of the crowd" [9] emerging, but to solidify this, the test should be performed on a larger, more representative group of users. It is also clear that Mapping 3 if especially ineffective, even though this is the only one where a direct 1 to 1 mapping is employed.

In the end this results do seem to confirm the hypothesis formulated earlier in this paper. Users perform very differently when different mappings are applied, even though the factual difficulty of the test remained unchanged. The way users approached the system was far more compatible with Mapping 1 after having used the system individually first, compared to the other two mappings.

To further solidify the relevance of Ambient mapping in this system, it would be interesting to perform the test with larger groups of nodes connected to a hub to see if the a possible "wisdom of the crowd" effect continues to emerge. This effect should become stronger as more nodes are connected as a larger crowd is reached and included in making decisions for navigation through the maze. Exploring even more diverse mappings would could also provide interesting results. The applied mappings are relatively simple and easy to identify after studying them, the effect of more abstract mappings therefore could still provide previously unobserved effects.

Future plans

Outside of being research object the drawing machine has some interesting peculiarities around it. It has the ability to switch rapidly between a very direct relation between the nodes and the hub to a semantic one. For example: when drawing the hub could help straightening lines by lagging briefly behind the node. Or it could, on an even more abstract level, convert simple smiles into complex faces with the defined emotion.

Concluding: the system has potential to some interesting and unique behaviour that is not necessarily interesting for this research, but does provide a very interesting design challenge that can relate to it: How can this direct to semantic mapping be applied while maintaining a rich interaction. It is safe to say that the drawing machine deserves more elaboration and will be expanded upon following this research.

CONCLUSION

The main goal of this paper was to to explore if Ambient Mapping should be defined as a fifth mechanism of growth that supports rich interaction in a growing system. Even though the observation was made that Positioning Ambient Mapping into CRIGS seems to be counter productive at first sight, the currently limited results seem to supported the notion that Ambient Mapping holds value within CRIGS.

(IoT) systems are often used in environments that are rapidly changing, causing them to be used in multiple scenarios. different scenarios could illicit radically different expectations from a system. Therefore it can be vital for Rich Interaction in a Growing System to anticipate these scenarios. The four previously defined Mechanisms of Growth support this growth at the tangible end of the system, in their unique way. Ambient Mapping instead places the support for growth in the reaction or feedback a user gets. Because the user is not notified of this change, choosing the right mapping is vital.

Multi-scenario, Dynamic or Ambient Mapping does not seem to be defined in the relevant literature at this point but can be relevant in providing a system that can grow and still maintain richness.

Future plans and discussion

The most obvious issue with this research is the lack of application at this point. Practically applying Ambient Mapping to a design project could help support the value of it and further define if and how it provides value to CRIGS. It could therefore be meaningful to apply the prototype driven exploration employed in the definition of the current mechanisms of growth. Ideally, getting the insights of many students into the application of the concepts elaborated in this paper would help place it very practically in the way mechanisms of growth have been defined currently. The creation of multiple applications of Ambient Mapping in CRIGS by multiple members of the research community seems like the most valuable way to position Ambient Mapping further.

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REFERENCES

1. Djajadiningrat, T., Wensveen, S., Frens, J., & Overbeeke, K. (2004). Tangible products: redressing the balance between appearance and action. *Personal and Ubiquitous Computing*, *8*(5), 294-309.
2. Dourish, P. (1999). Embodied interaction: Exploring the foundations of a new approach to HCI. *Unpublished paper, on-line: http://www. ics. uci. edu/~jpd/publications/misc/embodied. pdf*.
3. Dourish, P. (2001). Seeking a foundation for context-aware computing. *Human–Computer Interaction*, *16*(2-4), 229-241.
4. Fiebrink, R., Morris, D., & Morris, M. R. (2009, April). Dynamic mapping of physical controls for tabletop groupware. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 471-480). ACM.
5. Follmer, S., Leithinger, D., Olwal, A., Hogge, A., & Ishii, H. (2013, October). inFORM: dynamic physical affordances and constraints through shape and object actuation. In *UIST* (Vol. 13, pp. 417-426).
6. Frens, J. J. (2006). Designing for rich interaction: Integrating form, interaction, and function.
7. Frens, J. W., & Overbeeke, C. J. (2009). Setting the stage for the design of highly interactive systems. *Proceedings of international association of societies of design research*, 1-10.
8. Frens, J., Funk, M., Lin-Lin Chen, Braun, J. (2016) CRIGS. *Project description*.
9. Giles, J. (2005). Wisdom of the Crowd. *Nature*, *438*(7066), 281.
10. Hemmert, F., Hamann, S., Löwe, M., Zeipelt, J., & Joost, G. (2010). Shape-changing mobiles: tapering in two-dimensional deformational displays in mobile phones. *CHI'10 Extended Abstracts on Human Factors in Computing Systems*, 3075-3080.
11. Ishii, H., Lakatos, D., Bonanni, L., & Labrune, J. B. (2012). Radical atoms: beyond tangible bits, toward transformable materials. *interactions*, *19*(1), 38-51.
12. Kortuem, Gerd, et al. "Smart objects as building blocks for the internet of things." *IEEE Internet Computing* 14.1 (2010): 44-51.
13. Lehrl, S., Gerstmeyer, K., Jacob, J. H., Frieling, H., Henkel, A. W., Meyrer, R., ... & Bleich, S. (2007). Blue light improves cognitive performance. *Journal of neural transmission*, *114*(4), 457-460.
14. Mennicken, S., Vermeulen, J., & Huang, E. M. (2014, September). From today's augmented houses to tomorrow's smart homes: new directions for home automation research. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (pp. 105-115). ACM.
15. Nakagaki, K., Follmer, S., & Ishii, H. (2015, November). LineFORM: Actuated Curve Interfaces for Display, Interaction, and Constraint. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology* (pp. 333-339). ACM.
16. Rasmussen, M. K., Pedersen, E. W., Petersen, M. G., & Hornbæk, K. (2012, May). Shape-changing interfaces: a review of the design space and open research questions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 735-744). ACM.
17. Seuntiens, P., Vogels, I., & Van Keersop, A. (2007). Visual experience of 3D-TV with pixelated ambilight. *Proceedings of PRESENCE*, *2007*.
18. Ullmer, B., & Ishii, H. (2000). Emerging frameworks for tangible user interfaces. *IBM systems journal*, *39*(3.4), 915-931.
19. Van Campenhout, L., Frens, J., Overbeeke, K., Standaert, A., & Peremans, H. (2013). Physical interaction in a dematerialized world. *International Journal of Design*, *7*(1).
20. Waddington, N. J., & Wakkary, R. (2010). Everyday Design Through the Lens of Embodied Interaction. In *GRAND Annual Conference* (pp. 2-4).
21. Weiser, M. (1993). Some computer science issues in ubiquitous computing. *Communications of the ACM*, *36*(7), 75-84.

22. Woo, J. B., & Lim, Y. K. (2015, September). User experience in do-it-yourself-style smart homes. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (pp. 779-790). ACM.

23. Zhang, B., Mor, N., Kolb, J., Chan, D. S., Lutz, K., Allman, E., ... & Kubiatowicz, J. (2015). The cloud is not enough: Saving iot from the cloud. In *7th USENIX Workshop on Hot Topics in Cloud Computing (HotCloud 15)*.