Affordances of Shape-Changing Interfaces: An Information Perspective on Transformability and Movement

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ABSTRACT

Affordances is an important term in the field of Shape-Changing Interfaces (SCI). But the field is challenged by a multitude of vaguely defined concepts around affordances such as dynamic, spatial, or tactile affordances. In line with this, Alexander et al [1] recently pointed to lack of theory as one of the grand challenges for SCI. This paper proposes a re-analysis of Gibson for resolving the conceptual cacophony in the field of SCI. Essential to the ecological approach to affordances, is that perception is dynamic and people pick up information through exploring objects and environments over time. From this perspective, affordances of Shape-Changing Interfaces become a matter of providing *Information* – through the design – regarding a) the interfaces’ ability to transform its shape and b) how movement suggests level of animacy. Through analyzing scholarly SCI prototypes, from this perspective, we provide an initial set of design strategies for affordances of shape-changing interfaces.

Author Keywords

Affordances, information, perception, perceptual learning, shape-changing interfaces, design

CSS Concepts

• Human-centered computing~Human computer interaction (HCI)

INTRODUCTION

“Shape-changing interfaces provide the opportunity to fundamentally transform human interaction with computing machines” - Alexander et al 2018

Alexander et al. [1] recently pointed out that one of the Grand Challenges of SCI is theory development. Taking on this challenge, this paper reflects on the current state of affairs regarding affordances and SCIs, and contributes a critique of the terminology around affordances related to shape-changing interfaces. In the research community focusing on Shape-Changing Interfaces (SCI), there seems to be a common sense, that SCIs offer something unique and that affordances is a useful term for articulating the qualities of these novel interfaces [9][45][43][51]. Several researchers have however added new qualifiers to articulate affordances of SCIs. This includes device affordances [7], haptic affordances [4], tactile affordances [9], physical affordances [55], material affordances [43], spatial affordances [8], just-in-time affordances [5], or handling and effector affordances [25][45], and dynamic affordances [9][21][44][51]. This paper revisits Gibson’s original work on ecological perception and affordances, as it offers a starting point for identifying and articulating what is at stake when objects suddenly start to change shape. This is done without re-inventing the term or adding yet another qualifier to the already long list.

In particular, the paper draws on Gibson’s concept of how information specifies affordances, and how this must be understood in the context of an active perceiver who learns over time [13][14]. The core proposition of the paper is that the emergence of SCIs does not call for additional theory or qualifiers, but rather an enriched conceptualization of affordances, which can be found through re-visiting Gibson. Secondly, through analyzing scholarly SCIs based on this elaborate conceptualization, we illustrate how SCIs often deploy certain design strategies to provide information regarding affordances of SCIs. In this way we illustrate how an elaborate theoretical foundation for affordances of SCI can inform the design of future SCIs.

RELATED WORK

Affordances is a well-established term in HCI and has also made its way into the area of SCI. In the following, we exemplify the rich terminology related to affordances in the fields of HCI and SCI.

A VARIETY OF AFFORDANCES IN HCI

Since Norman in 1988 introduced the concept of affordances to the field of HCI [38], the term has been widely adopted in the HCI community [11][25]. Over the years, it has also been appended with a wide range of qualifiers in order to articulate the meaning of the term in the context of HCI, and to make it more operational for design.

Frustrated about the impoverished deployment of the term affordances in the field of HCI, Norman himself elaborated on the term affordance introducing perceived and real affordances [40]. The latter are actually affordances in a Gibsonian sense, whereas the first are not. Other authors have also contributed with more qualifiers. Gaver [11] introduced perceptible, false, hidden, sequential and nested affordances, where hidden affordance are used to describe an existing affordance without available information, and a sequential affordance is picking up an affordance that reveals information about other affordances. Additional examples include physical, cognitive, sensory and functional affordances [19], time affordances [6], basic and complex affordance [52] motivational affordances [58], collaborative affordances [2], operational, instrumental and need-related affordance [3], instrumental, handling, effector, aggregation, and learning affordance [25], and a distinction between basic and complex affordances [59], just to mention a selection. Some of these concepts are similar, yet different as e.g. Gaver draws upon Gibson's concept of information which is not included in Norman's account of affordances. Others have brought in additional theoretical foundations for articulating affordances, such as Activity Theory [3][25]. However, these enriched theoretical foundations of affordances have with few exceptions [45], yet to make it into the SCI approach to affordances.

A VARIETY OF AFFORDANCES IN SCI

The SCI community has built on top of these varieties with its own range of affordances qualifiers, aiming in different ways to address specific characteristics of SCI. The terms often indicate that the physical changes in shape alters the object affordances: Suh et al. describes this as “*by changing the shape of the controller, different physical affordances are provided to distinct users*”[49]. Nakagaki et al. argues that changes in shape “*provide rich affordances for tangible interaction*” [36], p. 40. Others point to the spatial and temporal aspects of the shape change for example indicating that “*users quickly learned to take advantage of the spatial affordances of the shape-display*” [8], p. 2781, or that the shape change results in “*...on-demand tactile affordances on touch screens*” [9], p. 419 or “*...just-in-time affordances, ultimately supporting more relevant interactions which could not have been predicted by their original designers*” [5], p.3433.

Dynamic Affordances in SCI

Among the qualifiers added to affordance within SCI, dynamic is the one that is predominantly used e.g. [9][21][44], in many cases in connection with physical

affordances e.g. [9][23][32]. The term “dynamic affordance” seems to originate with Ishii et al. [21], where it is used to describe how a physically dynamic form can “*inform users of its transformational capabilities (dynamic affordances)*” [21], p. 47. The paper describes dynamic affordances as utilizing dynamic materials that are bidirectionally coupled with a digital model. It is argued that affordances change as the interface alters its shape such that the user is continuously informed about the state of the interface and the functions it can perform. This work has roots back to at least the mid 1990's and the MIT group “Things That Think” as well as the seminal Ishii & Ullmer [22] paper on tangible bits, which points to rich affordances. Later, Ishii and colleagues discuss physical affordance and just-in-time affordance [5]. Parkes & Ishii [43] mentions material affordance. The term dynamic affordances has since then been picked up by a variety of authors, e.g. [9][33][48][51]. Despite its widespread deployment, however, the concept is often used without reference or definition. One of the few definitions of dynamic affordances are provided in Rasmussen et al.'s [44] review of SCI, where the term is introduced as: “*...dynamic affordances, that is, perceived action possibilities that change with changes in shape*” (p. 743).

Dynamic affordances are sometimes presented as being in contrast to static affordances. Follmer et al. [9] for example describe dynamic affordances as changing in relation to demand, in contrast to “static affordances”, which have fixed physical states. While the paper presents an extensive exploration of affordances, it does not provide a definition beyond stating that it explores “*Dynamic Affordances which can transform shape, size, location and orientation, in addition to being able to appear and disappear.*” [ibid], p. 417. A similar view on dynamic affordances as being in contrast to static ones can be found in both Leithinger et al. [32] and Nakagaki [36]. Other examples focus on how changes in the form provides new action possibilities, such as [23][55]. The dynamic nature of affordances is also highlighted in Alexander et al. [1] under the heading of adaptive affordance, which is a seemingly synonymous term.

Although the idea of dynamic affordances seems prevalent and obvious in the field of SCI, there are at least three problems in relation to the current use of the term. 1) Most of the research does not provide a clear definition of dynamic affordances, nor do they discuss how these are different from existing definitions of affordances 2) They typically draw upon a rather narrow conceptualization of affordances and most often conceptually conflates communication, information, and affordance, 3) They are used mainly as analytic concepts and it is not clear how they inform design.

REVISITING GIBSON'S NOTIONS OF AFFORDANCES

When Gibson originally introduced the term affordances, it was part of a wider terminology and theory. Gibson's

ecological approach has at least three major ideas relevant for SCI, that sets it apart from other theories [12][13][14]. One is the concept of affordances, but the other two are information and perceptual learning, and the last two being largely ignored especially in SCI but also to some extent in HCI. In the following we revisit Gibson's original work in an effort to strengthen the theoretical foundation of affordances of SCI.

Affordances and Information

On a general level there seems to be an almost universal consensus on the definition of Gibson's concept of affordance, namely that *"the affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill"* [12], p. 127. In addition, the concept refers to the relationship between the environment and the animal. However, despite this general agreement, the concept of affordances is in many cases used without reference to the underlying concepts, such as information, perception and learning. This omission can for example be seen in Norman, who states that *"I came to appreciate the concept of affordances, even if I never understood his other concepts, such as "information pickup." He and I disagreed fundamentally about how the mind actually processes perceptual information (that phrase alone would infuriate him)."* [40], p. 39. The quote reflects a fundamental disagreement of the perceptual processes between Norman and Gibson. However, as has been pointed out by for example Gaver, [11], affordance is not operational without understanding some of the more fundamental concepts connected to affordances, such as the perceptual system's ability to pick up information available in the environment about objects and events, (see also [3][59]).

For instance, it is essential to the ecological approach that all perception is temporal. This means that whenever we talk about picking up information, we really mean that the perceptual system (in a body system) makes adjustments, focuses, approaches or retreats, and moves around over time to pick up the available information. Information is not something that "just" comes to the perceiver, but something he or she actively or perhaps even creatively goes looking for. Objects are nested within other objects and events, and can be perceived when engaged with on different levels over time. According to Gibson [13], we do not perceive time as such, but objects in events over time. Shapes changing over time are events affording specific actions. A cat lying down purring, might afford petting, but when it moves away, you might be wise to leave it alone.

Affordances are thus the potential relationship between the individual and the environment revealed as they move around in the world or as the objects of the world come into sight. Thus, information is what specifies the world around us, it is available for perception and can be picked up by an active perceiver exploring its surroundings. Information is structured in the energies of e.g. light (available for visual

perception), vibrations (touch and hearing) or chemical diffusions (smell). Without *structures* there is no specification [14]. This is what makes perception "direct" in Gibson's sense of the word. The information available specifies both possible actions, events, relations between "things", and motion and movements, such as disappearance and destruction or appearance and creation [15]. Norman's concept of signifiers [41] is sometimes seen as interchangeable or perhaps surpassing the concept of information. However, we contend that signifiers contribute to the muddle of affordance for a few reasons. First signifiers are cues to be processed or interpreted. Second, signifiers are easily conflated with "signs" and symbols. Thirdly, Norman treat signifiers as a "communication device". Further discussion of this would be worthwhile, but outside the scope of this paper.

Perceptual Learning and Active Perceiver

The question is then, how does information become available for the active perceiver? The process of picking up this information has in HCI often been treated as a way of almost magically knowing how to do things (through looking at them). Turning to a Gibsonian understanding, being able to "pick up" information is a matter of perceptual learning, as the process of picking up information from the environment is a skill that we acquire through differentiation, and, thus, experience [12]. The work in perceptual learning is primarily done by James Gibson's wife, Eleanor Gibson. Perceptual learning is to learn what, when and how to do something. Our experiences with particular objects or instances make it possible to notice more and more details, differences, locations, behaviors and possibilities by acting with and observing the thing in focus. This is what James and Eleanor Gibson termed *"differentiation"* [17]. Perceptual learning is a lifelong process, where we as infants and children learn to perceive our world, in relation to our body, explore and test the environment, thereby increasing perceptual knowledge, about the world and ourselves. And as adults we continue to learn and acquire new experiences. We have learned that when we do certain things, the world reveals itself in certain ways [12]. Consequently, information is not in itself more or less precise, but rather it is our ability to distinguish between coarser or finer layers of information that can be better or worse.

Based on this wider conceptualization of affordances, we turn to analyse a non-actuated everyday object which can transform its shape - a foldable table. With this we exemplify how Gibson's concepts of affordances and information can be used to articulate affordances of objects capable of shape transformation and we highlight the challenges associated with the concept of dynamic affordances. Next, we analyse scholarly examples of SCIs to illustrate and contextualise the broadened conceptual framing, as well as to provide specific examples that can support the design of future SCIs.

AFFORDANCES AND SHAPE CHANGE: THE CASE OF A FOLDING TABLE

The ability to change between two or more physical shapes is often highlighted as being a central and unique quality of SCI. However, SCIs are not the only types of artefacts that have this potential. A range of artefacts in our everyday life, although not actuated, have the possibility of changing between two or more physical shapes, such as for example folding tables and chairs, pocket knives and umbrellas.

However, since affordances are typically exemplified through everyday objects such as door handles, hammers or interactive objects such as knobs and switches [39], it does raise the question of how the ability to change the shape affects the affordances of an object? To answer this question, we start with an example of an everyday object which has two distinctly different shapes - a folding table, see Figure 1. The folding table can have a collapsed suitcase-like shape, or a table shape - each of which offers different action possibilities. As illustrated, the folding table has different affordances and information specifying them.

What is worth noting, however, is that the object, regardless of its current state offers the user to be a table or to be packed up. The affordances of the object are thus, comprised of what both shapes offer the user. Although the information available for the “hidden” state, when the table is in state A, is the information on how to transform it to that state - state B - and vice versa. The example illustrates that objects can have multiple states and multiple affordances, but that each state provides different information specifying the available affordances of the object.

When in state A, the form still hints at its transformational capabilities, through the line separating the two parts, the hinges and the locking mechanism.

Figure 1. Affordance and Information of a Folding Table

From Dynamic Affordances to Affordances and Information

If we turn to SCIs, the concept of dynamic affordances e.g. [9][21] addresses the ability of SCI to change between different physical shapes (partly) through self-actuation. However, the challenge with expressing the possibility of

changing shape, as dynamic affordances, is that simply because something changes, does not imply that the changes in affordances are more dynamic than something that does not. The fact that an object is capable of changing shape, does not challenge Gibson's notion of affordance, as what changes, when the object changes shape, is simply the information available about the affordances. Moreover, in the SCI literature, dynamic affordances are sometimes juxtaposed with static affordances e.g. [9], and in this way it points to two hypothetical kinds of objects; one where the affordances are fixed and static, and one where they are changing, i.e. dynamic. From the perspective of Gibson's notion of affordances [12], this distinction is problematic, as it implies that the affordances of the so-called static objects do not change. They do. A chair is not only for sitting on, but can be used for standing, throwing, hanging things on, holding doors, and taming lions. The concept of affordances always implies dynamics of the behavioral side, as emphasized by e.g. [54]. Re-stating Gibson's notion of affordances, they are relationships between the environment and the animal, and thus they are inherently dynamic, also when it comes to so-called static objects like a chair. But the possibility to pick-up an affordance requires that there is a stable mode of behavioral possibilities with the object that can be picked up by the actor, otherwise we would not talk of affordances at all. If a chair only occasionally affords sitting on, we would require information specifying when, where and how it affords sitting and not sitting. This is also the case for SCI. When a certain shape of the interface is inviting to a certain action, from an affordance and information perspective, we argue that we need to design for the availability of information specifying that possibility of behavior. Therefore, the challenges for SCI is not to make affordances “dynamic”, they inherently are. Instead it is to make the new possibilities available for an active perceiver through providing relevant information. If we use this perspective to look at a scholarly example of a SCI, which describes its ability to change between different shapes, as dynamic affordances - then LineForm [35] is a relevant example, see Figure 2. However, the shape does not alter the affordances offered by the artefact - it still offers wrist wrap-ability, grab-ability or hold-against-face-ability, regardless of what shape it is in, but changing the shape significantly alters the information available to the user, about these possible actions.

Figure 2. LineForm [35] in four different shapes: lamp, wristband for haptic feedback, phone block to dial information, and telephone receiver to make a call (Photo by courtesy of Ken Nakagaki and Sean Follmer).

Information specifying affordances

As affordance and information are often conflated within both HCI and SCI, we highlight the distinction between the two using LineForm as an example. LineForm consists of sections that alternate between two different rotation axes - as illustrated by the sketches in Figure 3. Observing LineForm without the cover, the physical form specifies information about the transformational capabilities of the design, as well as the specific rotational capabilities of each section. When the textile cover is added to the design, as it is presented in the paper [35], the loosely draped textile cover hides the underlying mechanical structure, see figure 3. The design still affords the users with the same action possibilities, but the cover hides the information available, which specifies the division of the object into sections, and the ways in which the object is capable of transforming. Using Gaver's notion [11] we can call it a hidden affordance.

Figure 3. Right: LineForm original design with and without textile cover [35] (Photo by courtesy of Ken Nakagaki and Sean Follmer). Left: Sketches illustrating construction principles.

Figure 4. Lineform re-design sketches from an information perspective. Left: Divisions into sections. Right: Divisions and rotation axes.

Figure 4 illustrates two re-design sketches of LineForm illustrating how it would be possible to provide information about transformational capabilities through design. The redesigns focus on supplying users with information specifying two aspects, namely: the division into sections (Figure 4, left) and their rotation axes (Figure 4 right). Notably, regardless of the changes made to the exterior of LineForm, the object still offers the same action possibilities to the user, the designs just offer more or less information about them. Having illustrated how the information perspective can elaborate our understanding of affordances of SCI, based on specific examples, we move on to ask more generally, how the expanded perspective of affordance and information can alleviate the particular opportunities and challenges of SCI? Drawing upon earlier research Alexander et al [1] defines SCIs as interfaces which I) Use physical change of shape or change in materiality as input and/or output II) Are interactive and computationally controlled. III) Are self-actuated and/or user-actuated. IV) Convey information, meaning, or affect.

In line with this definition, we focus on two specific perspectives on information and affordance, which are significant to consider for SCI, namely a) '*information and transformability*' and b) '*information and movement*'. Transformability (a) follows from I), and movement (b) relates to III). II) and IV) are inherent in the scope of SCIs that we address and use to exemplify the points. 'Information and transformability' deal with understanding how the SCI can provide information about its transformability, while it is not transforming shape. I.e. how can we perceive that a potential form is possible, when the object is static in its current form? 'Information and movement' deals with understanding how motion can provide information, reflecting on the significance of self-actuation in understanding affordances of SCIs. I.e. how can and do we perceive the trajectory and "intent" of the object as it is actuated, either by itself or by a user? Of course, these two perspectives are highly related as transformation of SCIs also implies movement. Thus, the suggested distinction is primarily analytical and targeted the specific characteristics of SCIs, and does not reflect a fully encompassing theory about information. In the following, we deal with transformability and motion separately, as they highlight different aspects of the design.

INFORMATION AND TRANSFORMABILITY

This section focuses specifically on information specifying the transformability potential of shape-changing interfaces, when the interface is not moving. Viewing SCI in this perspective, information related to transformability can specify other available shapes or simply the ability to transform. When designing SCIs, it is often difficult to provide the user with information precisely specifying the other available shapes. However, what is often seen in SCIs is that static shape provides information, which specifies the ability of the shape to transform - but not exactly into which shape, nor that it is done through actuation.

When designing SCI with the aim of specifying their ability to physically transform, designers can take advantage of common, well-known objects and how we have learnt to pick-up a range of different types of information from everyday objects specifying that they can transform shape in different ways.

Information Specifying the Ability to Transform

Re-visiting scholarly SCIs based on this perspective, we can see how they make use of different strategies for providing information that specify the ability to transform. To illustrate this, in the following we outline four different strategies as they are found in scholarly SCIs; 1) structure, 2) material, 3) actuation mechanisms, and 4) form. This is not meant as an exhaustive list, but as a starting point, which can serve to inspire designers working with affordances of SCIs.

Structure specifying transformability potential

Figure 5 illustrates two different SCI examples, which in different ways utilize the structure to specify the transformability potential. In addition, the figure illustrates how the design of SCIs can leverage elements from everyday artefacts, such as folds or hinges as a way to provide a familiar frame of reference for understanding the transformability potential. Ninja track [26] is built up of sections hinged together, specifying the affordance of bendability - and by making the hinged sections visible, the user is provided with information about its potential to transform - although the fact that it is actuated might come as a surprise. The ReFlex phone [46] similarly rely on a familiar structure - pleats or origami as a way to specify its transformability potential.

When utilising structure as means of specifying transformability potential, designers might look to the wide range of objects in our everyday life that is capable of being reconfigured, such as for example; foldable rulers, sofa beds or telescopic antennas [47], as sources of inspiration.

Figure 5. Top left: Ninja Track [26] (Photo by courtesy of Yuichiro Katsumoto). Top right: ReFlex Phone [45] as examples of the structure specifying the transformability potential. Bottom: Examples of references to everyday objects.

Material specifying transformability potential

Figure 6 illustrates two examples of using the material to specify transformability potential, leveraging peoples' experiences with the affordance of different types of materials, such as for example whether they are rigid or flexible. The CoMotion bench [18] is designed using two somewhat unconventional upholstery materials - spandex and elastic. Both materials are known as materials with stretch-ability affordance, but they are rather unfamiliar in the context of a bench. This conflict of information might provide information about the potential of the bench to transform, but also gave rise to people questioning its "benchness". During deployment it was found that people often touched it, to test its stability before sitting down [18].

Figure 6. Top left: CoMotion [18]. Top right: Weight and volume changing device [37] as examples of materials specifying transformability potential. Bottom: Examples of references to everyday objects.

Similarly, the Weight and volume changing device [37] illustrated in Figure 6, specifies its transformability potential through a stretchy material. Both examples use the visual and haptic information as a means of specifying the transformability potential through material.

Actuation mechanism specifying transformability potential

A few examples of SCI showcase the actuation mechanism, either fully or partly, and thereby indicating the possibility to transform. Examples include Animate Mobiles [20], see Figure 7, which consist of a transparent acrylic box with a visible servo motor inside. Another example is Amphorm [29], a Kinetic Sculpture where the actuators are visible between each of the transparent actuated layers.

Figure 7. Animate mobiles [20] (Photo by courtesy of Fabian Hemmert) as an example of actuation mechanism specifying transformability potential. Bottom: Examples of references to everyday objects.

By exposing the actuation mechanism, people who are familiar with different types of actuation mechanisms, such as servo motors or linear actuators are supplied with information both about the transformability potential, as well as the fact that the object can be computationally actuated.

Form specifying transformability potential

Lastly, a possible strategy for specifying the transformability potential might be found in the form and shape of the artefact. The physical design can through its shape and composition of the different elements express a sense of motion, a shape can for example be considered static or dynamic, or provide a sense of balance or imbalance in the design. Shape can also be imbued with a sense of motion through association, for example with nature.

One example that can illustrate these principles is the Sensitive Rolypoly [10], when the motion is stopped in different stages of the continuous movement. The in-between state illustrated in Figure 8, have an unsettled nature

Figure 8. Sensitive Rolypoly [10] (Photo by courtesy of Johanna Fulda) as an example of form specifying transformability potential.

either moving down or up, creating a sense of imbalance in the shape.

A different approach can be found in the MIT bioLogic project [57], where the transformations are based on processes found in plants and organisms. Here, the transition from one state to another provides information about the ongoing processes and the potential for reaching a desired state or shape. An example is a leaf slowly uncurling when covered in hot water, providing the user with information about the transition from water to tea [ibid]. The dynamic change of shape, as also found in nature – albeit often at a slower pace – makes it possible to see both process and result at a glance.

Utilising either dynamic forms or imbalance is rarely seen as a strategy to specify a transformability potential of SCIs, but could provide an additional avenue for specifying transformability potential that awaits further exploration.

INFORMATION AND MOVEMENT

Being Self-actuated and/or user-actuated is one of the defining characteristics of SCIs [1]. In line with this, learning from Gibson, one of the most basic events are the changes of layout in the environment [12]. Gibson describes these as “*alterations of the shape of the surfaces*” [ibid], p. 95, and this includes deformations, displacements and shift in orientation. Overall, there are two important kinds of movement: One is made by inanimate objects, the other by animate objects [ibid]. The two types can be distinguished by how movement is initiated and how they move. The movements of inanimate objects have to be initiated by an outside force – e.g. in order for a ball, a skateboard and a car to move, they all have to have external force applied, for example by a human, the wind or a motor. All of these “passive motions” result in a predictive kind of motion behavior, as they move along physically and environmentally determined paths. Animate objects on the other hand can initiate movements on their own accord, making them less predictable, as their motion paths are not determined by an outside force, but by the object itself.

These kinds of movements can be called active motions. In terms of affordances, the importance of perceiving objects as either animate and inanimate is that they offer distinctly different action possibilities to people. For example, if an object comes towards you, perceiving whether it is animate or inanimate make rather different action possibilities and consequences available. If it is inanimate it might be grasped, avoided or deflected, whereas if it is animate it might be hugged, hit, avoided or just expected to stop by itself.

SCIs pose a challenge in terms of how we experience our surroundings - as being either animate or inanimate, as information of SCIs in many cases specify them as belonging to both. Despite being inanimate objects, the movements of some SCI give the impression of some level of animacy – take Hemmert et al.'s animate mobile phone [20] as an example (Figure 7), the clear acrylic box with a servo inside is, based on its shape, clearly an inanimate object, but the way that it reacts to an approaching hand can be perceived as if it was a “real” animate object, akin to a cat or dog.

Figure 9. Top: Movements of Thrifty Faucet [53] (Photo by courtesy of Fabian Hemmert). Bottom: Examples of references to everyday objects.

Similarly, Thrifty Faucet [53], see Figure 9, is an actuated water tap which was used to test 15 different motion patterns, seeking to cover expressions for reward and positive feedback up to denial. However, when evaluated, Togler et al reports how “*Astonishingly many people envisioned in the beginning, that the tap would splash them with water and therefore acted carefully in face- to-face situations with the tap*” [ibid], p. 44.

Analyzing SCIs from the perspective of information and movement, we identify three different ways that the

movements of SCI can specify information on level of animacy. These are 1) how the movement is initiated, 2) the movement character and its trajectory, 3) the sentence of the movements. Again, these are not suggested as an exhaustive palette, but rather as a starting point for designers in understanding the aspects to consider when designing for intended information pick-up regarding SCIs.

Movement initiation specifying (level of) animacy

Designing SCIs as more or less animate through movement initiation, is a matter of considering when and how the movement occurs in relation to the users’ interaction, and the sense of control of the movement, offered to the user.

A range of examples of SCIs rely on users directly interacting with the SCI, and the shape-change occurring as an immediate response, such as for example NinjaTrack [26] (Figure 5), and KnobSlider [27] (Figure 10), where shape change occurs as a result of pushing a button. In these examples, the user gets the sense of applying the force/turning it on and thus, the movement does not seem initiated by the object, but rather by the user. Other examples seek to give the user the sense of the objects being animate, by using indirect interaction, such as in Animate Mobiles [20], where the movement occurs as the user reaches out for the phone, or the CoMotion bench [18] where the movement of the bench seat is experienced as being outside the user’s control.

Consequently, when designing SCI, the nature of the interaction with shape-change, in terms of initiation of the movement, have consequences beyond usability of the interfaces, as it also contributes to specifying information to the user regarding how animate or inanimate the object is.

Figure 10. Movements of KnobSlider [27] (Photo by courtesy of Anne Roudaut)

Movement character and trajectory specifying (level of) animacy

The way the SCI moves and the trajectory of the movement can serve to specify information to the user about its (level of) animacy. E.g. Disney’s 12 basic principles of animation [24] specifies how certain movement characteristics can serve to induce an “illusion” of life, such as easing in and ease out of movements. While, inanimate objects on the other hand, are specified by movements that do not change

direction or speed, unless they come into contact with other visible objects, have predictable trajectories following predetermined paths, and only move as a direct result of forces impacting them.

ReFlex phone [46] (Figure 5) illustrates the impact of whether or not the movements occur with or without speed or direction changes, as the movements that simply result in a simple up or down movement of the surface of the phone, does not appear as animate, but as soon as the surface moves up and down, changing direction and speed without impact of any outside force, the phone seems to jump up and down as if an animate object seeking to grab the users attention.

Related to this is the manner in which the movement starts or stops, whether the movement is eased in or out of, or has an abrupt start or stop. As an example, the change in shape in KnobSlider [27] occurs abruptly as the user pushes the button, and with a constant speed, rather than starting and ending slow as seen in movements of animate objects. The Ripple Thermostat [42] on the other hand, eases in and out when it changes direction, perceived as a more life-like movement.

Figure 11: Movements of RippleThermostat [42] (Photo by courtesy of Anke van Oosterhout).

While inFORM [9] utilises both changes in direction and easing in the movements of the physical pixels, the linear path limits the animacy of the object, whereas movements that have a curved path such as seen in the case of PneuUI [55] where the pneumatic soft composites are capable of moving and changing shape in smooth curved paths.

Furthermore, animate objects often have a degree of variation with regards to how they move, the same movements are not carried out in exactly the same manner. The majority of SCIs rely on prespecified movement patterns causing the SCI to move in a consistent and identical manner, such as NinjaTrack [26] (Figure 5) and KnobSlider [27] (Figure 10). The Sensitive Rolypoly [10] (Figure 8) on the other hand moves in response to the noise level in the room, and thus rarely moves in exactly the same way.

Designers of SCI thus, have a range of different movement parameters they can adjust, if seeking to specify the interface as acting in either an animate or inanimate manner, such as for example the movement trajectory and path, how the

movement starts, stops or changes direction, and the consistency in the movement repetitions.

Sentient specifying (level of) animacy

The way the SCI moves and to what extent the user is offered control over the movement specifies information about how sentient the SCI is and thereby its (level of) animacy. Movements can specify a sense of “sentient” in the design, for example through mimicking movements linked to certain emotions, or by designing movements in a manner where they express an intentionality - for example where the artefact has an opinion regarding which shape it should be in.

Looking to the framework presented by Rasmussen et al.[46], it illustrates how with SCIs, users do not always have full control over what and when the SCI changes shape, as seen in for example Spiky Starfish [30], ActuEater [34] and CoMotion bench [18]. Allowing the SCI (some) control over the movement and shape change, can be used to specify intentionality of the object, for example by preventing or encouraging/discouraging actions. As an example, the Spiky starfish [30] counteracts the users’ actions, as it seeks to prevent the users from getting a cigarette - offering nicotine gum as a substitute. Both the ActuEater [34] and the Ripple thermostat [42] (Figure 11) seek to encourage a specific behavior, through the way they move – users of the ActuEater were keen to give it “... *further values believing it had a hidden agenda of some good intention and meaningful purpose*” [34], p. 6. The CoMotion bench [18] disrupts the people sitting on the bench, seeking to spur an encounter between strangers. Each of these examples use the movement to express a certain intention on behalf of the artefact to the user, thereby giving it a sense of sentient.

Another strategy has been to use movement as means of specifying information about emotions in an abstract form, such as for example Tan et al. [50], who have used a small box with a cylindrical extrusion on top capable of moving up and down and adjusting the angle, which successfully were able to communicate emotions, such as sadness, fear, happiness, and surprise. The Inflatable Mouse [28] can alter the tempo and intensity of the inflation and deflation of the shape, in order to express the sense of the mouse breathing calmly, as if taking a nap when not in use, or as having a rapid heartbeat to increase the tension of a situation when the user is playing a game. Similarly, Animate Mobiles [20] use the speed and angle of the top surface of the phone to as a way to specify the phone’s relation to the user, ranging between expressing affection and aversion. Where the previous examples rely directly on the users seeing the movements of the SCI as that of a living creature, capable of showing emotions, aversion or just breathing, then the Ripple Thermostat [42] is more abstract in the way movement is used. The work explores both shape change and haptics as a way to express dominance or submission, and the study suggests that despite the abstractness, of both force

feedback and shape change, they can successfully convey affective meaning during the user-system dialogue.

DISCUSSION

To specify, or not to specify information?

While there are plenty of good reasons for considering how the physical form and movement can specify affordance information to users of SCI - there might also be situations where hiding this information could be a quality in the design. Take the CoMotion Bench [18] as an example, while the material used in the design to some extent does specify transformational capabilities, the design intentionally sought to obscure that the bench could change its shape. The bench could have been designed in a manner, where the design specified more clearly that the bench had transformational capabilities, such as for example showing the actuators hiding beneath the covering cloth. However, doing so would detract from the intention of the design – namely that of creating an encounter between strangers, where the mystery of what was happening played a part in sparking the encounter.

Overall, of course designers of SCI shall take into consideration what the aim of the design is. If the aim to create a SCI where users can easily understand what it offers and how to use it, then specifying information about this is key. However, if curiosity, surprise, wonder or magic are experiences and qualities aimed for, designers should perhaps purposefully avoid specifying information. The point with the paper in these terms is to create awareness around these issues and not to prescribe how to design.

Affordances as a Generative Perspective

Through connecting affordances with Information, Perception and Learning, and illustrating how existing SCIs are designed to provide information about affordances, we seek to contribute to affordances becoming more of a generative perspective, rather than an analytic perspective, which serves to articulate what went wrong. Of course, the strategies and perspectives offered are not exhaustive and need to be explored in order to see how they apply across different cases and can also be used more systematically to inform design processes. Future work should explore this through working systematically with the strategies and perspectives to develop novel designs and to evaluate these designs in terms of how people perceive their affordances, i.e. their possibilities for action. In addition, it would be relevant to study how the strategies and exemplars can support designers in designing for affordances.

CONCLUSION

As SCIs emerge as a new type of interface, the concept of affordance has attracted attention as a gateway to conceptualize the possibilities for action. This paper suggests that including Gibson's wider conception of affordances, can serve to alleviate the current conceptual conflation surrounding the term in SCI, as can be seen from the plethora of signifiers added to the term affordances, and

the general lack of definitions and theoretical foundations. Gibson emphasizes that perception is about meaning, and affordance is the very basic aspect of perceiving our meaningful surroundings. We learn this by moving around, seeing, touching, smelling and listening to the objects and events in the environment. Designing SCIs from the perspective of affordances, implies focusing on *how* we perceive meaning as affordances, and what we attend to when learning about them. In this article, we suggest that the concept of information is vital in understanding affordances and in designing for them, in the sense that we need to design for information pick-up regarding in particular SCIs ability to transform shape and to move more or less autonomously. Based on this wider conceptualization, we re-visit scholarly SCIs, and map out different strategies that designers can deploy when designing for information pick-up. We distinguish here between information about two kinds of motions in SCIs; information about potential transformations from one state into another, and information through movement in terms of initiation, character, trajectory and sentience that specifies the level of animacy of the SCI. These distinctions are not meant as exhaustive, but serve as a starting point. Finally, based on scholarly SCI research prototypes, we illustrate how we can draw upon well-known phenomena in everyday objects, when designing for future shape-changing interfaces.

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