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Interaction Frogger: a Design Framework to Couple Action and Function through Feedback and Feedforward

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ABSTRACT

In this paper we present a design framework to analyze person-product interaction in terms of the couplings between the person's action and the product's function through the use of inherent and augmented information, i.e., feedback and feedforward. Instead of using the notion of 'coupling' in an abstract sense, our framework tries to give six practical characteristics for coupling action and information, i.e., time, location, direction, dynamics, modality and expression. Unifying action and information on each of these aspects makes the interaction intuitive. The framework invites and challenges designers for the exploration of couplings towards embodied freedom of interaction.

General Terms

Design, Theory.

Keywords

Interaction models, tangible user interface, feedback, feedforward, design framework

1. INTRODUCTION

In previous DIS papers we reported research on designing emotionally rich interaction [12, 13]. We designed an alarm clock, which elicits rich expressive behavior and demonstrated that it is able to read your emotional state from the way you interact with it. In conclusion we argued that expressing emotions to an interactive product presupposes freedom of expression and thus freedom in interaction. In our product design approach this freedom of interaction is based on the exploitation of the rich perceptual motor skills of the user [2]. In the alarm clock we realized this freedom of interaction by allowing for a myriad of ways to set the 'factual' information, i.e., the wake up time, instead of a fixed procedure.

Freedom of interaction is not only important in the realm of emotionally intelligent products, but also in the broader notion of 'embodied interaction'. 'Embodied interaction' is described by

Dourish as "the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" [3: p.126] and as being central to tangible computing. To change interactive systems towards embodied interaction, Dourish gives two suggestions that closely relate to 'freedom of interaction'. First he suggests to organize the "...interaction as an informal assemblage of steps rather than a rote procedure driven by the system". This resembles our notion of offering the user a myriad of ways to achieve a product's functionality. From his analysis of traditional interfaces [3: p.50-51] we take a second point as being important for freedom of interaction: - no single point of control or interaction. In addition to these points, we believe that in order to design for free and playful interaction, actions need to be reversible, so the consequence of an action can easily be undone [10]. In conclusion we state that in order to achieve freedom of interaction designers need to offer interaction that:

- takes full advantage of a person's perceptual motor skills
- offers a myriad of ways to achieve a product's functionality
- allows the person to act at multiple points at once
- allows for easily reversible actions

Freedom of interaction is of course not unlimited. One should realize that freedom of interaction does not equal freedom of action. While unbounded action possibilities might allow for freedom of expression it is useless without the proper reaction of the product. To avoid the user is getting lost, (s)he needs information on how their actions and the product's function are coupled. Dourish states this as follows: "... support the process of improvised, situated action by making the immediate circumstances of the work more visible. The insight here is that the setting in which the work emerges includes the current state of the system; the system should make information available to the user to guide their activity moment by moment." [3: p.160].

In the remaining of this paper we explain how the user's action and the product's function can be coupled to generate this guiding information, while still allowing for 'freedom of interaction'. We start with an analysis of a mechanical product that allows for freedom of interaction and where the user's action and the product's function are naturally coupled. We identify six aspects of action and function i.e. time, location, direction, modality, dynamics and expression. When action and function are unified on each of these aspects, they appear naturally coupled. In contrast, in interactive systems action and function often are not unified on these aspects. Whilst this brings many advantages for new functionality (e.g. remote operation, programmability) it often results in non-intuitive interaction. To restore intuitive interaction

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in electronic products the user needs information to guide his actions towards the intended function. Therefore we focus on the creation of information through feedback and feedforward and distinguish three types of information: functional, augmented and inherent. These different types of information are the elements that can link action and function together by making couplings on the six aspects. We present a framework that illustrates these different coupling possibilities and illustrate how different interaction styles fit into this framework. Based on this analysis of interaction styles we argue for a more tangible approach. This approach aims to enrich both the action possibilities and the related inherent feedback and feedforward to allow for richer couplings between action and function. The approach is amply illustrated using product examples.

2. Coupling action and function

In most mechanical products the appearance, the action possibilities, the action and the function are all naturally coupled which allows for intuitive interaction. To illustrate the issue of acting at multiple points at once and a natural coupling between action and function, we use the example of a pair of scissors.

Imagine sitting at your desk cutting several images from a page of a magazine. The cutting comes about through the coordinated use of scissors, paper and your desk. You might use the scissors with your dominant hand, while your non-dominant hand is used to orient the page appropriately and you use the desk as a support to handle the size of the page. These are all brought together to achieve the task; you act at multiple points at once. The design of a pair of scissors (appearance) fits our perceptual motor skills. And, when using them to cut paper, moving your thumb and finger towards each other (action) is naturally coupled to a change of orientation of the blades (reaction) and the incision these blades make in the paper (function). When the blades are dull or the paper is too thick the resistance of the action also informs the user about the failure of making a proper incision.

This example shows the direct and natural coupling between the user's action and the product's functional feedback through the unification of action and reaction on the following six aspects; time, location, direction, dynamics, modality and expression. Unifying action and reaction on these six aspects can be seen as an operationalization of intuitive interaction. In the following section we explain the six aspects.

2.1 The six aspects of natural coupling

There are six aspects taken from the physical world, i.e. time, location, direction, dynamics, modality and expression, which describe characteristics of both the action and the reaction. Unifying action and reaction on each of these aspects makes the interaction intuitive. The example of cutting paper with a pair of scissors is again used to introduce and explain the six unification aspects.

2.1.1 Time

The product's reaction and the user's action coincide in time.

There is no delay in time between moving your thumb and finger towards each other (action), the change of orientation of the blades (reaction) and the incision these blades make in the paper (function).

2.1.2 Location

The reaction of the product and the action of the user occur in the same location.

The paper is cut where the scissors touch it.

One can argue that the location of your fingers and your hand do not coincide with the cut of the paper. But because the scissors become an extension of your hand when cutting the paper (Heidegger's concept of 'ready-to-hand' or 'zuhanden' [in 3, p.109]), you act through the scissors at the same location as the paper is being cut.

2.1.3 Direction

The direction or movement of the product's reaction (up/down, clockwise/counterclockwise, right/left and towards/away) is coupled to the direction or the movement of the user's action.

The direction of the incision is the same as the direction of the blades following the orientation of the cutting hand or the paper. Moving the scissors further into the paper makes for a longer incision.

2.1.4 Dynamics

The dynamics of reaction (position, speed, acceleration, force) is coupled to the dynamics of the action (position, speed, acceleration, force).

The speed of the cutting action determines the speed of the incision being made. A smooth and continuous motion of cutting and orientating the paper, results in a smooth and flowing incision. Likewise, a consecution of discrete cuts and reorientations of the paper results in an accordingly choppy incision.

2.1.5 Modality

The sensory modalities of the product's reaction are in harmony with the sensory modalities of the user's action.

When the blades touch and cut the paper this can be seen, heard and felt. In nature the relations between different modalities are natural and in harmony, e.g., the touching of two objects can cause a sound or moving an object can be visually perceived.

2.1.6 Expression

The expression of the reaction is a reflection of the expression of the action.

The user can express himself in the cutting of the paper. For example when the user is in a hurry, it probably results in imprecise and hurried actions. This is reflected in the incision in the paper. In mechanical products the aspect of expression is often strongly related to the aspect of dynamics.

The six unification aspects are not limited to mechanical products but can also be used to couple action and reaction in electronic products.

2.2 Reality hits back

Unlike in purely mechanical products, in which action and reaction are naturally coupled, in electronic products this does not have to be the case.

This is fortunate in the way that electronic products do not have to follow the tight coupling laws of the physical world. This allows for programmable products (action and reaction are not unified on the time aspect), remote controls (action and reaction are not unified on the location aspect) and enjoying music without constantly having

to touch the strings of a guitar yourself. Electronic products instill moments of magic and surprise that seem to surpass the laws of nature and physical causation.

It is unfortunate, on the other hand, that an interface is needed to mediate the user's action to the product's function. This mediation hinders an intuitive interaction, because there is no longer a natural and direct coupling between action and function.

In product design, designers striving for intuitive interaction can reinforce a natural coupling by unifying action and reaction on as many aspects as possible. But as more functionality is added to electronic products full unification on all the aspects may be difficult or even undesirable to achieve because intuitive interaction needs to be balanced with technology, ergonomics, production costs or aesthetics. For example, if we consider adjusting the volume in audio equipment we could strengthen the coupling between the action and function by uniting the location of the control with the location of the loudspeaker. From a comfort point of view, this may be acceptable for a portable audio-system but it would be rather awkward for a home stereo system in which the speakers occupy the corners of the room. Another example is the making of coffee. Unity in time of the action indicating a need for coffee and getting the coffee is technologically possible for an instant coffee dispenser but not for an espresso machine. When it is not possible for designers of electronic products to establish direct couplings between action and function information is needed. Information that can guide the user's actions towards the intended function. This is the area of feedback and feedforward.

In the next section we focus on these issue of feedback and feedforward and distinguish three types of information: functional, augmented and inherent.

3. Feedback

Feedback is one of the most common used design principles in interaction design next to visibility, constraints, mapping, consistency, and affordances [9]. Feedback can be defined as 'the return of information about the result of a process or activity' [American Heritage Dictionary]. In interaction design this seems to be interpreted as 'any type of returned information will do'. The following example illustrates the different types of returned information.

*When you push the on/off button to turn on the television...
...you feel it move inside the housing, you feel the resistance of that button, you hear and feel a click and release the button.
A red light next to the button lights up. Slowly the screen lights up, you hear a voice and you can make out the 9 o'clock news.*

In this example different types of feedback can be identified: the click of the button, the red light and the actual appearance of images on the screen and sound from the speakers. They are all forms of information the user receives about the effectiveness of his action. Usually when a subdivision of feedback is made, it is done on a sensorial basis, i.e. auditive, tactile, verbal and visual. Although this is useful when discussing sensory richness or multi-modality, there is a categorization that underlies the sensory. We distinguish three other forms of feedback: functional, augmented and inherent feedback.

3.1 Functional Feedback

"...Slowly the screen lights up, you hear a voice and you can make out the 9 o'clock news."

When the user receives this information from the television it is clear to him that his actions were successful, that his needs and desires to watch television are met. This information relates directly to the function of the product, it is the actual purpose of the product. Functional feedback is therefore defined as the information generated by the system when performing its function, e.g. sound, light or motion. As one product can have multiple functionalities and features, functional feedback should be viewed in respect to the needs, intentions and desires of the user. It is the effect in the world the user wants to achieve. When functional feedback cannot be naturally coupled to the user's actions additional information is needed.

3.2 Augmented feedback

"...A red light next to the button lights up."

In the television example, because there is not a direct coupling in time between the action of pushing the button and the appearance of an image, the designers opted for adding the red light. The information that the user receives from this light is called augmented feedback. The term augmented feedback found its origin in the field of the psychology of learning [8] and refers to information not coming from the action itself (which is inherent feedback), but from an additional source. Since it is not coming from the action itself, but from an additional source, augmented feedback appeals more to the cognitive skills of the user instead of appealing to the perceptual motor skills.

In product design this kind of feedback is usually added to inform the user about the internal state of the system through the use of Light Emitting Diodes, Liquid Crystal Displays and added sounds. It can indicate 'stand by', 'waiting', 'sleeping', 'processing' etc.

3.3 Inherent feedback

*"When you push the on/off button to turn on the television...
...you feel it move inside the housing, you feel the resistance of that button, you hear and feel a click and release the button..."*

In the example of turning on the television the displacement, the feel and sound of the button when pushed is inherent feedback. Inherent feedback is the information that is returned from acting on the action possibilities and therefore appeals primarily to the perceptual motor skills of the user. A definition can be found in the field of the psychology of learning where Laurillard defined inherent feedback as "Information provided as a natural consequence of making an action. It is feedback arising from the movement itself." [8]. In product design this form of feedback was usually treated as a by-product of the choice for the controls. But as the awareness of the multi-sensorial character of interaction grows, designers do not consider only the visual appearance of a control but also its sound, touch and feel.

4. Feedforward

Feedback is the information that occurs during or after the user's action. But before the user's action takes place the product already offers information, which is called feedforward. The same three division of inherent, augmented and functional can be applied to feedforward as well.

4.1 Inherent feedforward

Inherent feedforward, like inherent feedback is related to the action possibilities of the product and the perceptual motor skills of the person. It is the information that communicates what kind of action is possible (pushing, rotating, sliding) and how this action can be carried out (the amount of force that is possible, which parts of the body etc.). Inherent feedforward can be viewed as a limited interpretation of the concept of affordance [4], i.e. where the action possibility of the control is considered, regardless of the function of the product.

4.2 Augmented feedforward

When the user receives information from an additional source about the action possibilities, or the purpose of the action possibilities, it appeals to his cognitive skills (for example through words, pictograms or spoken words). This information is referred to as augmented feedforward.

Examples range from on-screen messages indicating what to do (figure 1), to lexical or graphical labels communicating the purpose of the action possibility.



Figure 1: Augmented Feedforward. The display of mobile phone informs the user about the appropriate action that needs to be taken to unlock the keypad.

4.3 Functional feedforward

Functional feedforward goes beyond the action possibilities and their specific purpose and instead informs the user about the more general purpose of a product and its functional features. Product designer can draw on concepts such as product semantics [7] and on making the functional parts visible [9] to inform the user about the functionality of the product. For example, the speakers and a screen on a black box informs the user about the audio visual functionalities of the product.

5. Framework

In the previous sections we introduced the different types of information the user can receive from an interactive system, i.e., inherent, augmented and functional information which are illustrated in figure 2.

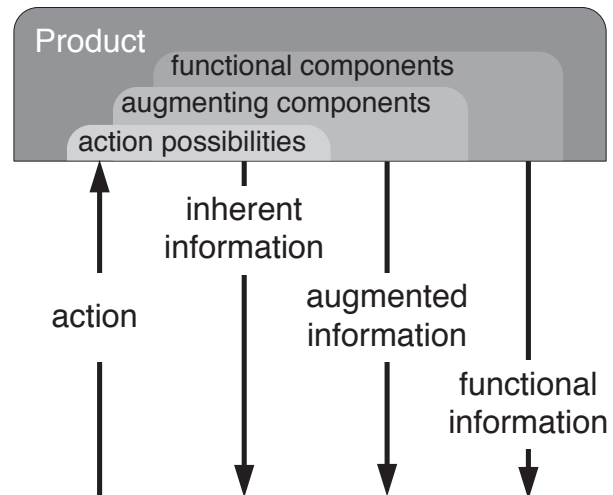


Figure 2: The different types of information that an electronic product can offer to guide the user's action towards the intended function.

We also introduced the six aspects of a natural coupling between action and reaction, i.e., time, location, direction, dynamics, modality and expression. Coupling the user's action and the different types of information, on each of the six aspects, constitutes a new interaction framework. This framework is visualized in figure 7.

With this framework it is possible to illustrate the couplings that are representative for different interaction styles. The direct couplings between action and function supported by the inherent information taken from the example of a mechanical product, i.e., the scissors, are illustrated in figure 3 and marked with (1).

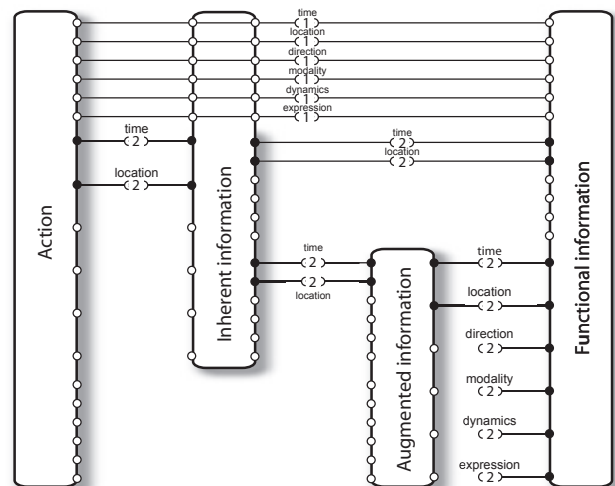


Figure 3: In a mechanical product action and function are bridged through inherent feedback

In contrast with the mechanical product, are the couplings in many current electronic products, which are also illustrated in figure 3 and marked with (2). While the electronic product's functionality does offer differentiations on most of the six aspects, the bridges between action and function are realized mostly through the unification of just two of the six aspects, i.e., time and location [Norman's concept of 'mapping'], which results in the use of appropriately placed buttons. Moreover, the bridge from action to

function is realized through augmented information, using LCD displays and the lexical labelling of action possibilities. Guiding the user's action towards the intended function therefore, puts a lot of effort on the user's cognitive skills.

In traditional WIMP interfaces (windows, icons, menu, pointers) the inherent information coming from acting on the mouse is only coupled to the augmented information via time and the direction (of the mouse and the pointer). So while acting on the mouse does give rich information, little of this richness is coupled to the GUI (augmented information) or the functionality (figure 4)

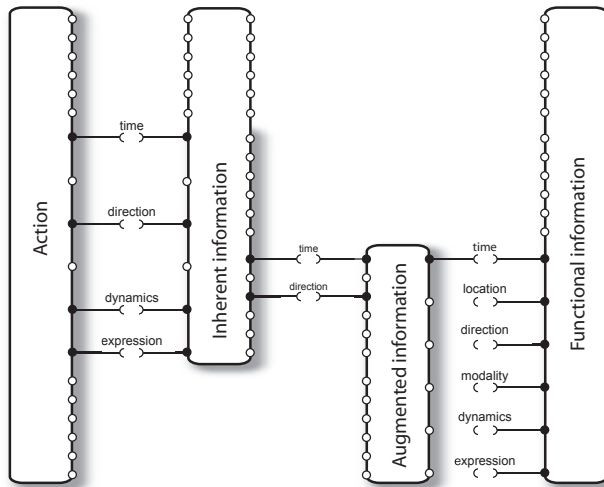


Figure 4: The information coming from acting on a physical input device, e.g., a mouse, is only coupled to the augmented information of a Graphical User Interfaces (GUI) on the aspects of time (of acting) and the direction (of the mouse movement). Often, the information coming from the GUI is unrelated to the functional information.

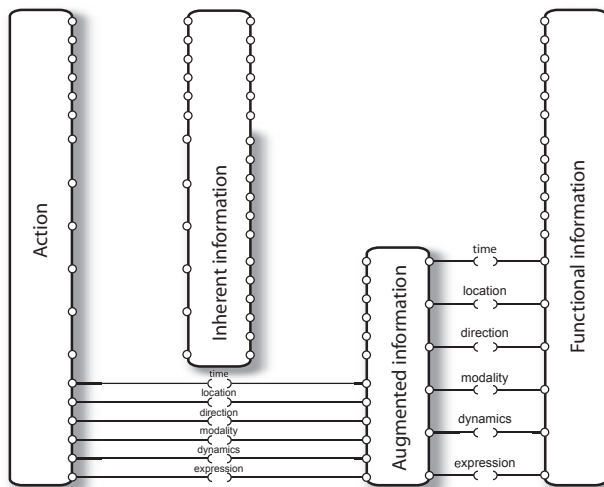


Figure 5: 'Natural User Interfaces' that make use of gestural and speech interfaces exploit the cognitive and perceptual motor skills of a person. Although rich in action possibilities these interfaces lack inherent feedback and feedforward and completely rely on a direct coupling between action and function or on couplings through augmented feedforward.

Other interaction styles focus on 'natural interaction' by making use of gestural and speech interfaces. They exploit the cognitive and perceptual motor skills of a person. Although rich in action possibilities these interfaces lack inherent feedback and feedforward and completely rely on couplings through augmented feedback and feedforward. The user receives little information about these action possibilities (figure 5). In contrast to these different interaction styles we argue for the following tangible approach (figure 6): Through a combination of enriching the action possibilities which exploit the human repertoire of actions and the inherent feedback based in the richness of the physical and tangible world the quality and number of possible meaningful couplings between action and function are increased. The following sections describe how this can be realized.

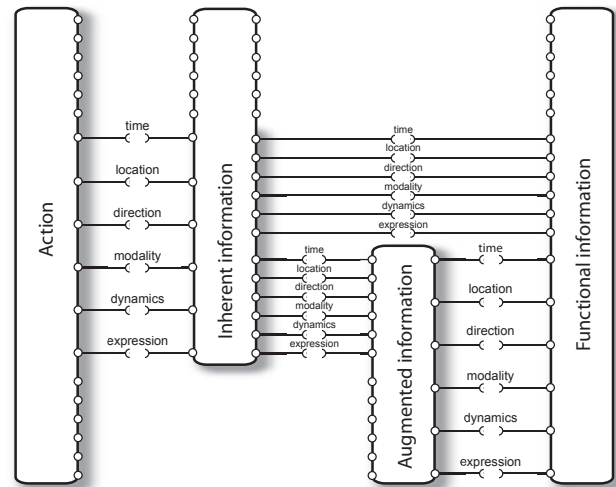


Figure 6: Through a combination of enriching the action possibilities which exploit the human repertoire of actions and the inherent feedback based in the richness of the physical world the quality and number of possible meaningful couplings between action and function are increased.

6. Coupling Action and Function: an alternative approach

How can this framework be used to restore natural couplings between action and function and strengthen intuitive interaction? The framework can be beneficial for interaction designers in two different ways. One way to use the framework is to improve existing designs by strengthening the couplings on the different aspects. The idea is that if a direct coupling between action and functional information is broken, because of technological, ergonomic, financial or aesthetic limitations, new couplings should be established in the design. These new couplings should bridge action and function via the use of inherent or augmented information. An analysis of the existing product can make them aware for example of the different locations where actions, inherent, augmented and functional information occurs. Relocating one or several of the sources can improve the intuitiveness of interaction. Actions that are only coupled to augmented information can be enriched by offering inherent information and therefore meaningful action possibilities as well. A simple example for a DVD-player can illustrate this enrichment. Instead of only offering augmented feedback through a display which states 'INSERT DISC', the designer can enrich the inherent information

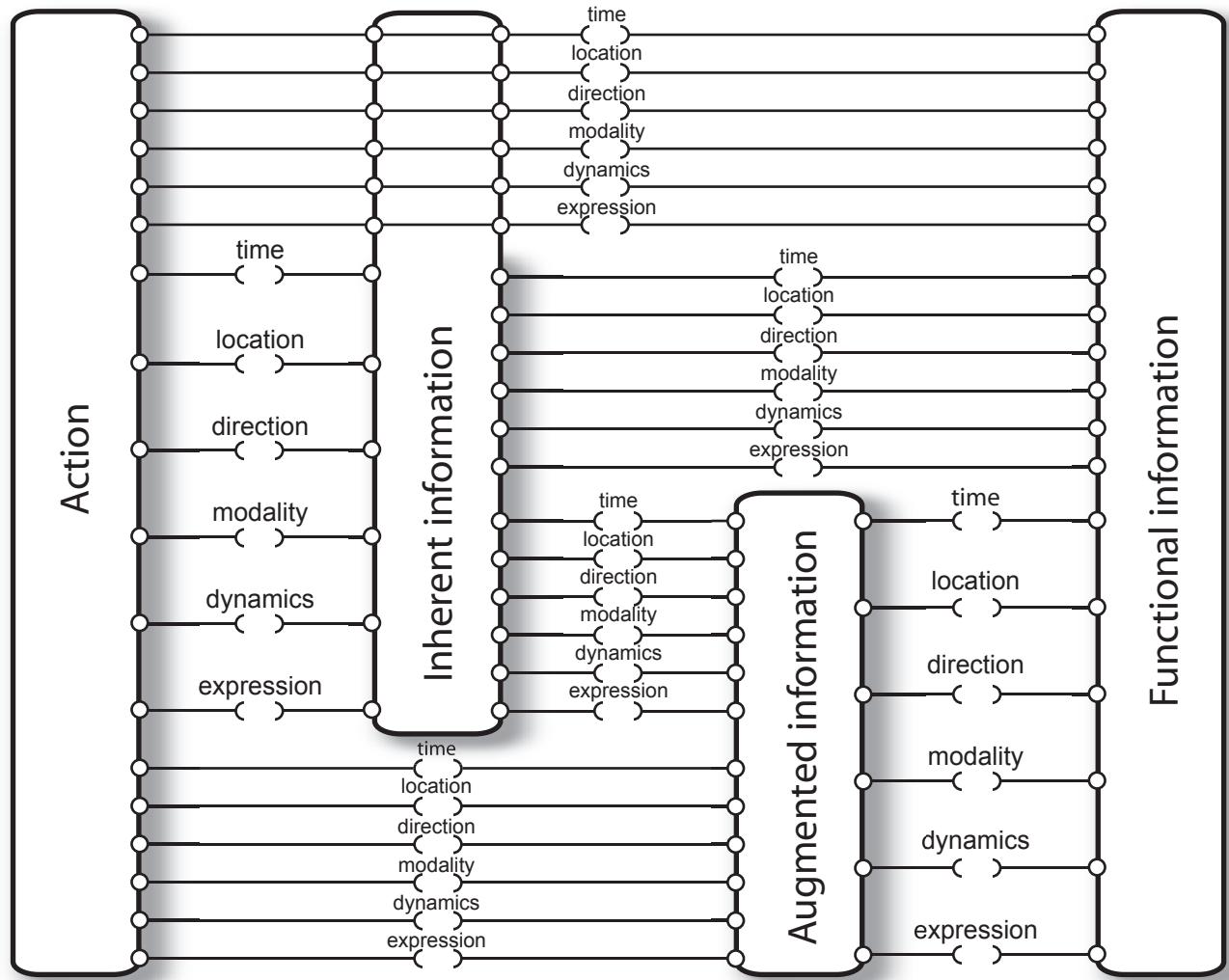


Figure 7: The Interaction Frogger Framework. A schematic interpretation of all the different coupling possibilities between the functional information and the user's action. The inherent and augmented information can be used as 'frog leaps' when direct couplings cannot be established.

and therefore a new action possibility by having the tray of the disc open at the same time. Another simple illustrative example is to improve existing designs by enriching the expression of the different types of information, which is illustrated in the example of the Light Emitting Diode of the Apple Powerbook®. The light is an indication of the sleeping state of the system and has the same expression as a relaxed breathing rhythm.

A more far-reaching approach is to use the framework to design for novel and more tangible interactions. The next three sections presents the issues of this tangible approach in the order of enriching the action possibilities first, followed by enriching the inherent information to end at the section where we discuss the coupling between inherent information and function. Of course in a design process these steps are iterative.

6.1 How to enrich the action possibilities?

Enriching the action possibilities which exploit the human repertoire of actions...

It seems that traditional interfaces of electronic products allow for only one action possibility, touching with a finger or thumb.

This action possibility only allows for an enrichment of coupling possibilities on the aspects of time and location.

To take full advantage of a person's perceptual motor skills, the designed action possibilities should also allow for diversification on the direction, dynamics, modality and expression of the action. And to stay in line with the other issues of freedom of interaction, the interaction should allow the person to act at multiple points at once, for example by allowing for two handedness (like in the example of handling both paper and scissors). To prevent that the user can only reach the functionality through one sequential order of actions the interaction should allow for multiple orders of actions. The interaction should also allow for acting on different action possibilities simultaneously (for example allowing for diversifications on the aspect of direction; pulling and rotating at the same time).

Merely enriching the action possibilities in person-product interaction is not enough. It should result in corresponding inherent information to bridge the action to the function.

Enrich action possibilities by allowing for differentiations in:

- time: allow for simultaneous actions
- location: allow for different locations where one can act
- direction: allow for different translations and rotations
- dynamics: allow for differentiation in speed, acceleration, force
- modality: allow for actions that can be seen, heard, felt
- expression: allow for differentiations of expressive action; symmetry, balance, flow, rhythm, tempo
- allow for one hand and two handed action

6.2 How to enrich inherent information?

In traditional product design the power of inherent feedback has been limited to the look, sound and feel of the controls. The sensory aspects of inherent feedback improved both the visual aesthetics of the product appearance as well as the haptic and auditory aesthetics of acting on the action possibilities. The power of inherent information does not have to end at providing aesthetically pleasing feedback during the action. When an action possibility offers inherent feedback, even *after* the action has ceased, it can blend into inherent feedforward to guide further actions towards the intended functionality.

6.2.1 Inherent Traces of Action

Feedback can occur both *during* and *after* the action. *During* the action there is always inherent feedback, since acting on the action possibilities always offers feedback.

The possibility of offering inherent feedback even *after* the action has ceased, depends on the designed action possibilities. When acting on appropriately designed action possibilities and the modulation of these action possibilities still exists after the action, new information is generated. In its simplest form it is evidence for the user that (s)he has acted on the action possibilities, as if it were a trace of the bygone action.

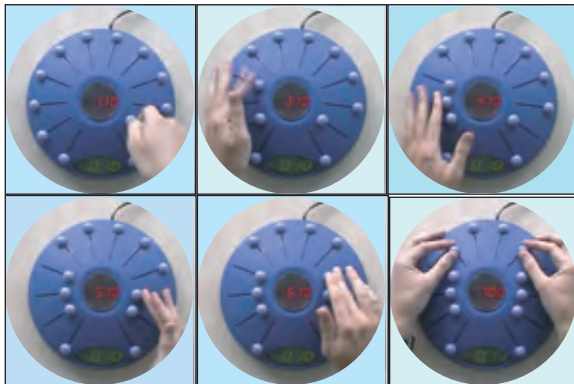


Figure 8: In our alarm clock design acting on the action possibilities give inherent feedback during the action. One can see and feel the action. The action possibilities of the alarm clock with the sliders give rich information about it being acted upon even after the action has ceased. The alarm clock carries a trace of the expression of the action. The modulated appearance of the slider alarm is evidence for the fact that it has been acted upon. It is a trace of a bygone action.

The trace in figure 8 is an example of inherent feedback where the modulation occurred on the aspect of expression. The modulation of inherent feedback can also occur on the other aspects. In nature

traces can carry information from the six different aspects: the vapor trail of an airplane carries information about time, location and dynamics. The trail from a snow boarder reflects the dynamics and expression with which (s)he carved down the mountain.

Acting on the action possibilities should result in a modulation of the inherent feedback on the six aspects which in return becomes feedforward for new action possibilities.

- time: actions that modulate the chronology of actions
- location: actions that modulate the location of the action possibility
- direction: actions that modulate the direction of the action possibilities
- dynamics: actions that modulate the dynamics (speed, acceleration, force) of the action possibilities
- modality: actions that change the modality of the action possibilities
- expression: actions that modulate the expression of the action possibilities, color, texture, shape, material, weight, symmetry, balance, flow, rhythm, tempo

Inherent feedback shouldn't be self-referent, where it only says something about the interaction between the user's actions and the action possibilities. What does matter is that it is coupled to the functional feedback. When the inherent trace is coupled to the functional feedback it offers information about the current state of the product, i.e. in which functional mode it is in. More importantly, because the acting modulated the action possibilities, information is generated; it is feedforward for how to *change* the current state of functionality.

Again, like merely enriching the action possibilities is futile, enriching inherent information without coupling it to the functional information will not improve intuitive interaction. In the next section we discuss how the inherent and functional information can be coupled.

6.3 How to couple inherent information to the function?

To couple the inherent information to the functional information the same six aspects can be used. Functional information should be analyzed on the following:

- time: when does the functional information appear
- location: where does the functional information appear
- direction: what direction (up/down, more/less, left/right) does the functional information have
- dynamics: what are the dynamics (position, speed, acceleration, force) of the functional information
- modality: what modalities does the functional information have
- expression: what expression does the functional information have

The extreme stance to improve intuitive interaction, regardless of technology, ergonomics, production costs or aesthetics, would be the following: If the functional information allows for a modulation on one of the six aspects, it should be coupled on that same aspect to the modulation of the inherent information and the action possibility. But, since designing electronic products is not solely about the intuitiveness of the person-product interaction, other couplings can and should be used. The decision of how to couple action and function is for the designers to take, not for the framework.

7. Conclusion

In this paper we presented a framework to analyze person-product interaction in terms of the couplings between the person's action and the product's function through the use of inherent and augmented information. We argued for a more tangible approach in order to create embodied freedom of interaction. How does this framework relate to other frameworks for tangible interaction?

The most common known frameworks for tangible interaction are those by Ullmer and Ishi [11] and Holmquist, Redström and Ljungstrand [5]. Recently two new ones have come up [1,6] building on the previous frameworks. Without going into the details and terminology of the other frameworks we believe there are three main characteristics that distinguishes our framework. First, while the other frameworks seem to focus on and are suited for describing TUI's that were already designed, our framework is primarily intended to support the designing of (tangible) interactive systems. Second, the framework acknowledges the role of the users in such a system by explicating their actions and the intended functionality. It describes the interaction between them on a information level using feedback and feedforward. Third, instead of using the notion of 'coupling', 'linking' or 'mapping' in an abstract sense, our framework tries to give six practical characteristics for coupling action and information. We hope the framework invites and challenges designers for the exploration of couplings towards embodied freedom of interaction.

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