# The Communicative Functions of Animation in User Interfaces

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## ABSTRACT
To develop a model that relates the purpose of the communication to the nature of the animation, we surveyed existing user interfaces that use animation, analyzed these uses with respect to type of animation and communicative function, and considered ambiguous or otherwise difficult cases. From this analysis, we constructed a matrix with appropriateness/inappropriateness values for all combinations of communicative functions and animation types covered by our survey. To illustrate how the model could be applied to graphical user interfaces and to assess the model's plausibility, we used the model to develop two versions of a user interface for an MP3 player.

## Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *graphical user interfaces (GUI), style guides, Theory and methods.*

## General Terms
Design, Human Factors, Standardization

## Keywords
Animation, design patterns

## 1. INTRODUCTION

> *Most people equate animated content with useless content.* —Jakob Nielsen [17]

Nielsen aimed his maxim at designers of user interfaces who use Flash with, as he put it, no purpose beyond annoying people. But designers who seek to use animation in a more integrated way, as an inherent part of the user interface rather than as something merely to catch the eye, find scant support in the interface-design literature. Developers can rely on resources that provide design patterns that, incidentally, use animation, but they are largely on their own if they seek more generally applicable, model-based advice. What do different kinds of animation communicate to the user? When should a designer consider introducing animation into an interface, or changing the nature of an existing animation in an interface? Answers to these sorts of questions, which touch on fundamental but relatively unexplored issues in the design of communication, require a more comprehensive and systematic connection between the form of different animations and what they communicate. In this paper we claim that the key communicative functions of animation in user interfaces can be characterized by a model that relates the purpose of the communication to the nature of the animation. Such a model could support designers who seek to use animation to expand the effectiveness and usability of user interfaces.

In this paper, then, we review the state of art with respect to models of animation in user interfaces, survey the uses of animation in existing and proposed user interfaces, present an initial model that describes the appropriateness of different animation types for different communicative functions, and illustrates how the model could be applied to graphical user interfaces by presenting two versions of a user interface for an MP3 player. We conclude with a discussion of the strengths and limitations of the model.



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## 2. REVIEW OF RELATED RESEARCH
Definitions of animation in user interfaces have ranged from specific to general. Vodislav [25] distinguished three categories of animation: (1) demonstration of program behavior, such as algorithm animation and data visualization, (2) feedback for users' actions to provide more realistic interaction, and (3) predefined animation, unaffected by either the user or the program. The latter category, the most conservative view, defines animation such as videos presented in help systems [e.g., 10, 21]. And to the three categories could be added a newer and often more annoying one: animation as a visual attractor [8], such as the elements of on-line advertisements that try to grab the viewer's attention—the very function that was the target of Nielsen's comment.

In this paper, we define animation broadly, with a view toward building as general a model as possible. As expressed by Thomas and Calder [22 (p. 199)], the "goal is to apply animation to the interface itself—to enhance or augment the effectiveness of human interaction with applications that present a graphical interface." Animation as an inherent part of the user interface, as opposed to a predefined animation, can reduce the user's cognitive load by enabling the user to follow and understand changes in the interface's appearance; that is, the interface uses animation to replace sudden changes with smooth transitions [5, 6]. These transitions can be spatial or qualitative. For example, developers of toolkits for interfaces with this sort of animation have provided motion, scaling, and change of color [13], and change of position and change of shape [9].

Providing the means for building animation into user interfaces leaves developers with a need for design guidance for the use of animation. Thomas and Calder [22] articulated a set of principles (attachment, reluctance, smoothness, and anticipation) that served as animation counterparts to Norman's familiar principles [18] for direct-manipulation interfaces. For example, the principle of attachment is that

> the objects being manipulated should at all times remain attached to the pointer, which maintains the impression that the user is always in control of the action. (p. 203).

Similarly, Chang and Ungar [5] articulated three main principles of animation: solidity, exaggeration, and reinforcement. For example, the appearance of solidity can be enhanced by motion blur and through proper treatment of arrivals and departures.

While these sorts of principles offer help in the implementation of animation, they fall short as help in the choice of the kind of animation. As Chatty [6] asked, what information should be coded by animation, and how? Should a change in information or in state be represented by a change in place? In shape? In color? In scale? In fact, there are few design rules for animation in user interfaces, and what design knowledge there is becomes more sparse and vague as animations take on communicative and metaphoric functions [6].

## 2.1 Design Patterns

One approach to answering these questions could rely on first principles, starting with the science of visual perception, eventually linking to semiotics. This approach was problematic for this initial research effort, in part because the scope of work would have been beyond that of an exploratory inquiry, and in part because the semiotics of change and movement do not appear to be well developed. As an alternative approach we chose to codify emerging practices, with a view toward understanding what implemented designs suggest about the implicit principles that underlay the developers' design choices. In many aspects of human-computer interaction, these design choices would be expressed as design patterns; as we discuss, however, for animation these resources remain limited with respect to communicative functions.

Developers of user interfaces can consult sources for design patterns for many kinds or components of graphical user interfaces. However, review of these sources suggests that they provide neither strong support for developers who use animation nor a generally applicable model of the functions of animation in human-computer interaction.

Reference materials that include design patterns for user interfaces (e.g., [20], [23]) provide patterns that help developers implement elements of the traditional canon of interaction elements, such as dashboards, navigation, and progress indicators. This probably should be expected, as design patterns represent known solutions to known problems. They do, in part, address animation, but this tends to be either as part of a traditional design pattern (e.g., scrolling) or as a specific technique (e.g., transitions). Review of these resources did not disclose animation patterns of general applicability, nor a higher-level model of when animation in its various forms would be useful or appropriate.

Several on-line sources, including Patternry [19] and UI Patterns [24], provide additional advice, in the form of design patterns, for developers of graphical user interfaces. While the patterns these sites provide may incidentally include animation as part of the interaction, the patterns are not patterns for animation. Rather, both Patternry and UI Patterns provide interaction- or task-specific patterns that solve specific interaction problems in ways that may or may not include animation. For example, Pattenry's "Tag an object" pattern solves the problem of a user wanting to attach his or her own keyword or set of keywords to an object for organization and later retrieval and does not appear to include animation. Patternry's "Endless scrolling" pattern solves the problem of the user needing to view large data sets where loading all the data at once would cause a notable delay in page load; because it involves scrolling, this design pattern necessarily includes animation, but the pattern's focuses on the interaction problem and its solution rather than providing a more abstract view of movement of text. UI Patterns offers design patterns that cover much the same ground—and in some cases almost exactly the same ground (e.g., the "Continuous scrolling" pattern solves the problem of user needing to view a subset of data that are not easily displayed on a single page).

## 2.2 Design Guidelines

Even if design of animation in user interfaces with respect to communicative function has not yet been codified through design patterns, developers can nevertheless consult the prescriptive advice of design guidelines.

Microsoft provides clear and helpful advice [16] for using animation in user interfaces, including some points about relating the animation to the task. Overall this documentation contains a mix of high-level concepts, several specific design patterns, and several implementation considerations. The design patterns are at the level of "Hover feedback: To show where the interaction point is" and "Attractor: To show that something needs the user's attention." Each design pattern describes Windows's animation vocabulary for the particular task. For example, the design pattern for hover feedback suggests displaying the hover effect (bounding rectangle, highlight, enlargement) with a fade in/fade out effect for smoothness, and the design pattern for attractor suggests flashing, moving, pulsing, glowing, and gleam. As noted, the advice is largely sound, and the patterns are useful and detailed. But even though they, implicitly, reflect broader ideas of the uses of animation, the advice and the patterns represent a set of design decisions specific to Windows; they do not represent themselves as or constitute a general model of use of animation in user interfaces.

Likewise, Apple's Human Interface Guidelines [3] provide correspondingly Apple-specific advice for developers of user interfaces. The advice is useful and clear, although it covers animation only implicitly, as when describing the use of drag and drop. The guidelines offer general design advice for graphical user interfaces (e.g., "Reflect the user's mental model"), along with ways to avoid particular design pitfalls (e.g., "Don't assign new behaviors to existing objects"). For developers who use animation, Apple does offer a guide, the Core Animation Programming Guide [2], but it focuses exclusively on implementation rather than use. That is, the animation guide and its related linked documents describe basic concepts involving the timing and animation classes. The animation guide assumes that the developers already have an animation design and now seek to implement it.

The Android Developer's Guide [1] does not address design patterns or guidelines for animation. Indeed, it covers animation only implicitly, as, for example, when it describes the API for dragging and dropping. Design advice is limited to accessibility, performance, responsiveness, and seamlessness, with, in the latter

case for example, explanations of how to avoid dropping data and avoiding overloading a single activity screen. Again, developers are free to use their design imaginations in creating user interfaces, but the developer's guide does not provide much support on how to use that freedom when using animation as part of the interaction.

## 2.3 Need for a Model

From this survey of design patterns and guidelines for the user of animation in user interfaces, it appears that developers have solid support for implementing standard interface elements that might incorporate animation but that they lack support for designing innovative interfaces that use animation in novel ways to improve the effectiveness of communication with users. What is missing is a model that could include the insights about animation inherent in the design patterns and in animation as it is actually used in interfaces and that would enable generalization of and extension from these specific cases. In short, the goal is to build a comprehensive model of the communicative functions of animation by generalizing from existing and proposed uses of animation in user interfaces.

# 3. AN INTIAL MODEL

To develop a model that relates the purpose of the communication to the nature of the animation, we surveyed existing and proposed user interfaces that use animation, analyzed these uses with respect to type of animation and communicative function, and considered ambiguous or otherwise difficult cases. From this analysis, we constructed a matrix with appropriateness or inappropriateness values for all combinations of communicative functions and animation types covered by our survey.

In this section, then, we review uses of animation in user interfaces, and then relate the types of animation to the communicative functions they embody, producing an initial model. In Section 4, we apply the model to illustrate its use in developing useful and usable interfaces.

## 3.1 Uses of Animation

In this exploratory study, we surveyed uses of animation in user interfaces across a wide range of interfaces and applications. We looked at GUIs for operating systems, office automation applications, video games, commercial Web sites, proposed future interfaces, and other specialized interfaces.

The GUIs for operating systems included Apple OS X, the Apple iPhone, Microsoft Windows, and Microsoft Surface.

Commercial Web sites surveyed included Fred Stuart (http://fred-stuart.com/FS.html), which uses animation to make digital objects appear and act like their real world counterparts, SectionSeven Inc. (http://www.sectionseven.com/), which uses animation to convey a book metaphor to navigate their client list and show off their portfolio, NOFRKS Design (http://www.nofrks.com/), which uses spatial animation to move smoothly from one page of the site to another, thus letting users feel like they are looking at one large page, and AgencyNet Interactive (http://www.agencynet.com/), which enables navigation by clicking on actual office rooms to discover different aspects of the company, with the animation flying into the room of choice so that users feel they are actually visiting and talking with the workers.

Our survey of proposed future interfaces included Microsoft Future Vision: Healthcare [15], Microsoft Future Vision 2019 [9], the 'Stand Up' Mac dock mockup [11], the Smart Inspector dynamic palette mockup [12], and Bumptop [4]. Other interfaces we studied included Compiz Fusion [7] and dynamic weather maps. Video games we studied included "Left 4 Dead 2" and "Mass Effect 2."

Such a survey is inherently non-comprehensive. The number of actual user interfaces employing animation is large, and even our team of three researchers working for months could not hope to cover more than a tiny fraction of these interfaces. We strove, then, to look at a range of different types of interfaces that would help us catalogue (a) broad types of animations and (b) kinds of communicative functions embodied in these animations, and then populate the entries in the animation-function matrix. Our resulting model thus reflects the selection of interfaces that we analyzed and should be considered as a starting point rather than as a model with universal truth. Indeed, as we note below in the discussion, we can already identify additional types of animation that could be employed in user interfaces.

From the interfaces that we studied, we catalogued instances of animation types according their communicative functions. For example, here is an excerpt of our survey dealing with change of shape and expression of context:

| |
|---|
| iPhone: The map page curls to reveal new controls but keeping the same context. |
| Interface Builder: The interface uses drag-and-drop morphing. |

Similarly, here is an excerpt of the survey dealing with change of color and expression of salience:

| |
|---|
| iPhone: An email message's alpha value is faded to zero when trashed |
| Microsoft healthcare vision: The ring around the prescription bottle pulses green when it is time to take the given medication. After it is taken, the ring turns to red. |
| Microsoft healthcare vision: The nerve of the eye the doctor is examining turns to green to indicate that it is important while the others are gray. |

From this catalogue, we summarized across animation types and communicate functions to produce high-level taxonomies. This exploratory process sought to minimize the number of categories in the taxonomies while preserving useful distinctions. We identified seven types of animation used in the interfaces we studied, as shown in Table 1. Likewise, we identified seven basic communicative functions served by the animations, as shown in Table 2.

The types of animation were relatively easy to distinguish. The categories did not overlap, except perhaps for gesture, and rather plainly covered all of the examples we had catalogued.

The communicative functions, in contrast, underwent repeated iterations as we distinguished, combined, and refined them. For example, some iterations combined status, importance and urgency as a single function, and some iterations included speech acts as a category. In our view, the problems of this process reflected uncertainty, ambiguity, and conflict among various models of communicative function. We faced a tension between over-generalization and over-specificity; the number of categories thus reflects both (a) the limits of generalizing from the roughly 60 observations that comprised our data and (b) our goal of producing practical guidance. The categories listed in Table 2 provided the greatest clarity in our analysis, but the categories' dynamic quality suggests that further refinement should be

expected as this research continues, even as they provide current practical assistance for developers of user interfaces based on animation.

**Table 1. Types of Animation.**

| |
|---|
| Change of place |
| Change of size |
| Change of color |
| Change of shape |
| Gesture |
| Rotation |
| Blur |

**Table 2. Communicative Functions.**

| |
|---|
| Signal different context |
| Signal different value |
| Signal different status |
| Signal importance, or urgency |
| Signal different function |
| Signal referent (pointing) |
| Signal salience |

## 3.2 Relation of Types and Functions

The seven animation types and the seven communicative functions provided the axes for a matrix that described the appropriateness of using a particular animation for a particular function. We judged appropriateness based on (a) the prevalence of the animation-function relationship in the user interfaces we studied and (b) the theoretical plausibility of the relationship given generally accepted models of affordances in user interfaces (e.g., [18]). We used the more theoretical approach particularly in assessing the appropriateness of animation-function combinations where instances of these combinations were sparse or non-existent in our survey of animation in user interfaces. We did not, however, necessarily assign low-appropriateness values for combinations with few instances in the survey. The survey's coverage stressed breadth rather than representativity, so the raw number of instances of a combination might not carry real significance. So where the number of instances of a combination was low, we assessed appropriateness using the affordance models.

The result of this analysis, our model of the relationship between animation types and communicative functions, is presented in Figure 1. Each of the cells in the matrix represents the use of an animation style for a communicative function, and the value of the cell represents our estimate of the appropriateness of the animation-function combination for effective user interfaces. A value of 2 means that the combination is highly appropriate, a value of 1 means that the combination is moderately appropriate, a value of -1 means that the combination is moderately inappropriate, and a value of -2 means that the combination is highly inappropriate. A value of 0 is neutral. In Figure 1 the shadings of the cells reflect their values; in this representation, brighter is better.

Before turning to an extended example of application of the model, presented below in Section 4, we first note a few of the model's broader implications. The model suggests that:

- No single animation style is appropriate for expression of all communicative functions.
- Some animation styles (e.g., change of color and change of place) have a greater number of appropriate uses than others (e.g., blur and gesture).
- Some communicative functions (e.g., function and referent) provide greater opportunity for inappropriate animation.
- Some communicative functions (e.g., status) have a clearly most-appropriate way of being expressed through animation.

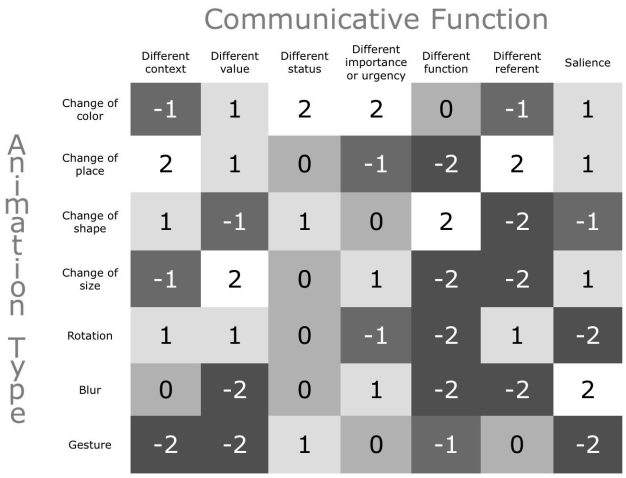


**Figure 1. Model of communication of animation.**

Some of the model's results seem to reflect common sense and common practice. For example, the model suggests that the most appropriate way of expressing value is through size. But the model also surprised us. For example, the model suggests that the most appropriate way of expressing salience is through blur, which few user interfaces use.

# 4. APPLICATION OF THE MODEL

To illustrate how the model could be applied to graphical user interfaces and to assess the model's plausibility, we used the model to develop two versions of a user interface for an MP3 player.

The first version, shown in Figure 2, uses [animation type, communicative function] pairs that, according to the model, have high appropriateness. For example, the model posits that the best way to signal a change of function is to change the shape of the relevant interface element; this pairing is plausibly appropriate because the different shapes can carry clear meanings. In the animation-appropriate MP3 player, the player's function (i.e., *play* or *stop*) is signaled by change of shape between an arrow and a square. Figure 2 thus depicts a user interface that should be among the most usable animation-based interfaces.

The second version, shown in Figure 3, uses [animation type, communicative function] pairs that, according to the model, have low appropriateness. For example, the model posits that one of the poorest ways to signal a change of function is to change size of the relevant interface element; this pairing is plausibly inappropriate because change in size does not clearly carry with it a new meaning related to function. In the animation-inappropriate MP3 player, the player's function (i.e., *play* or *stop*) is signaled by the same rectangle, just larger or smaller. Figure 3 thus depicts a user interface that should be among the least usable animation-based interfaces.

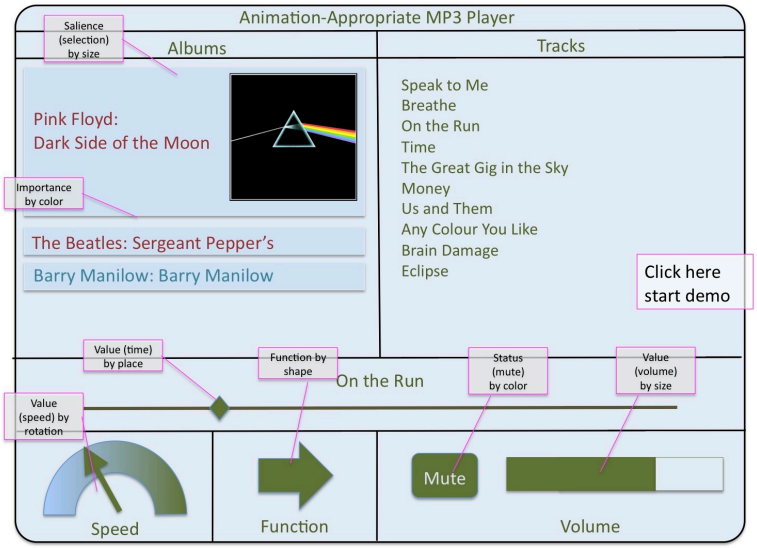


**Figure 2. Animation- appropriate user interface**

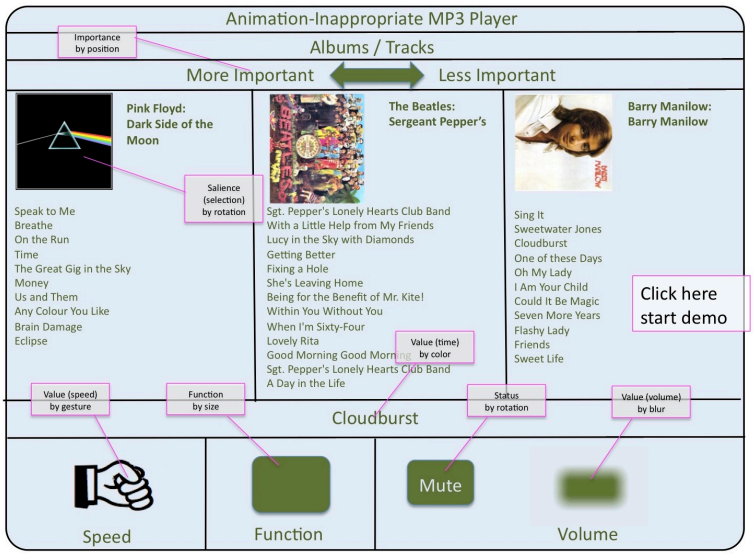


**Figure 3. Animation-inappropriate user interface.**

Working mock-ups of the user interfaces of animation-appropriate and animation-inappropriate MP3 players can be found at *http://www.cs.utep.edu/novick/mp3examples/*. In the mock-ups, which were implemented in PowerPoint, users can see the animations in action. In the authors' admittedly subjective opinions, the animation-appropriate interface feels intuitive and natural, and the animation-inappropriate interface feels awkward to the point of hilarity.

We now turn to a comparison of the specific animation features in the two mock-up interfaces, explaining how the design choices came from values in the model.

**Salience**. The MP3 player's major use of salience involved displaying which album was selected. The model suggests that change of size would be a moderately appropriate animation to communicate change of salience, so in the animation-appropriate user interface (henceforth "AAUI"), selection is indicated by expansion of the album's information block. The selected album has a larger bounding rectangle and shows the album cover; the unselected albums have been minimized. The model suggests that blur is a highly appropriate means of communicating salience, but in this case blur would have indicated selection of an album at the cost of making it more difficult for the user to select another album. Selection is not the only instance of salience, so blur would be useful in other cases.

The model suggests, conversely, that rotation is a highly inappropriate animation for salience, so in the animation-inappropriate user interface ("AIUI"), selection is indicated by a 90-degree rotation of the album cover. Comparison of the selection animations in the two interfaces confirms that change of size is more effective than rotation: it's immediately clear in the AAUI that the Pink Floyd album has been selected, while in the AIUI it's relatively difficult (a) to discern which album has been selected and (b) the identity of the unselected albums.

**Importance**. The model suggests that importance is most appropriately signaled by change of color. Accordingly, the AAUI uses color to distinguish "important" albums from "unimportant" albums, and a change in importance would be reflected in a change in color. In this example, the titles of the Pink Floyd and Beatles albums are presented in red, and the title of the Barry Manilow album is presented in blue. Conversely, the AIUI communicates importance through change of place, which the model suggests is moderately inappropriate. Indeed, the use of location as a signal of importance was so weak that we felt we had to include informational arrows in the AIUI explaining what the positions meant. Comparison of the two animation styles is easier in the full color of the PowerPoint mock-ups than in the monochrome of Figures 2 and 3, but to the extent that the color red is understood as communicating urgency, the color change should be more effective than a change in position.

**Value (time)**. The MP3 player includes a widget that indicates a value, namely the time elapsed as the track plays. The model suggests that change of place would be a moderately appropriate animation for communicating change of value, so the AAUI uses a moving slider to indicate elapsed time. The model suggests, too, that change of size is a highly appropriate animation for communicating change of value; our mock-up could also have used an expanding bar to represent elapsed time. Conversely, the model suggests that change of color is a moderately inappropriate means of communicating change of value, so the AIUI uses change of color, through shades of green, yellow, orange and red, to indicate elapsed time. It might have been possible to include color reference values (i.e., a sample of green to mean the beginning and a sample of red to mean the end), but the very awkwardness of doing so serves to underline how inappropriate change of color is for indicating change of value.

**Value (speed)**. The MP3 player also includes an indicator of the speed of playback; that is, the track might be playing faster or slower than normal. The model suggests that rotation is a moderately appropriate means of communicating change in value, so the AAUI has a dial with a rotating pointer to indicate playback speed. The model also suggests that gesture would be a highly inappropriate way of communicating value, so the AIUI uses gesture to indicate playback speed. In the PowerPoint mock-up, the fist icon extends its index figure one or more times, depending on the speed, alternating between the images in Figure 4. Comparison of the two animations suggests the clear advantage of

the rotation over the gesture: the rotation shows the change in speed right away while the gesture takes time (and the problem gets worse as the track speeds up!), and the value indicated by the rotated pointer appears to be immediately interpretable while the meaning of the gesture may depend on the user's ability or willingness to count the number of times the finger points.

**Figure 4. Speed gesture in inappropriate interface.**

**Value (volume)**. The MP3 player's last function is change of volume. The model suggests that change of size is a highly appropriate way to communicate change of value, so the AAUI indicates greater volume by increasing the length of a rectangle. Moreover, the rectangle is in a box, which provides users a reference value for the maximum volume. Conversely, the model suggests that blur is a highly inappropriate way to communicate value, so the AIUI indicates volume by the extent to which a rectangle is blurred. Figure 5 shows three values of volume, from low to high, indicated by blur. Aside from the fact that it's not clear whether greater blur means greater volume, the growing-shrinking rectangle in the AAUI provides a conventional representation of value that users will likely find easier to interpret.

**Figure 5. Value buttons in inappropriate interface.**

**Function**. Like other interfaces for playing audio, our mock-up MP3 players include a widget for controlling whether a track plays or pauses. The nature of the function—play or pause—is indicated by the representation of the button; as the button's function changes, its representation changes. The model suggests that change of shape is a highly appropriate way of communicating change of function, so the button in the AAUI presents an arrow or a pair of parallel lines, depending on whether the button's function is play or pause. Figure 6 shows these shapes. Conversely, the model suggests that change of size is a highly inappropriate way to communicate change of function, so the AIUI has a larger button to indicate play and a smaller button to indicate pause. Figure 7 shows these buttons. As the reader may easily see, the change in shape communicates function much more clearly than the change of size, in large part because we have canonical shapes for functions such as play and pause and do not have canonical sizes for these functions. Moreover, even if sizes could have such meanings, an interface using change of size would still be hard to use unless it included some sort of reference scale to judge size: without such a scale, how would a user know if a button were larger or smaller? And if such a scale were provided, it would clutter the interface in a way comparable to that of the reference colors for value.

**Figure 6. Function buttons in appropriate interface.**

**Figure 7. Function buttons in inappropriate interface.**

**Status**. The MP3 illustrates animation of change in status through its mute button. The model suggests that change in color is a highly appropriate means of communicating change in status, so in the AAUI clicking the mute button causes the adjacent volume bar to change color from green to gray (and, if the button is clicked again, back from gray to green). Conversely, the model suggests that rotation is a neutrally appropriate means of communicating a change in status, so in the AIUI clicking the mute button causes the adjacent volume bar to rotate from a horizontal orientation to a vertical orientation (and, if the button is clicked again, back from vertical to horizontal). Graying out an interface element conventionally indicates loss of availability or function, so the color change in the AAUI provides a readily apparent meaning. But rotation from horizontal to vertical does not appear to have a similar conventional meaning, and so the effect of clicking the mute button is more difficult to understand in the AIUI.

# 5. CONCLUSION

Our review of resources for designers of user interfaces indicated that although designers have access to design patterns for specific tasks and for proprietary design schemes, they lack access to a broader and more comprehensive model of the use of animation in user interfaces. From a survey of a range of user interfaces employing animation, we identified seven basic types of animation and seven basic communicative functions that they embodied. Using the information from the survey, we developed a model of the appropriateness of the various combinations of animation types and communicative functions. We then applied the model in developing two example user interfaces for an MP3 player, one using appropriate animation-function relations and the other using inappropriate animation-function relations. We explicated the use of the model in developing the example interfaces.

Our research suggests that the key communicative functions of animation in user interfaces can be characterized by a model that relates the purpose of the communication to the nature of the animation. Such a model would have three principal benefits: First, designers could apply the model to static user interfaces that could benefit from the use of animation. Second, designers could apply the model to critique existing use of animation in user interfaces. And third, designers could use the model to develop novel animation-based user interfaces. As our inappropriate-animation example suggests, not all innovation is necessarily useful. But through exploration of the design space, guided by the model, designers may be able to find new and useful animation-based user interfaces.

Aspects of our methodology, some less avoidable than others, limit the results of our research.

A first limitation involves the number and kind of the interfaces we surveyed in developing the model. Clearly it would be impossible to examine all interfaces past, current and proposed. But how many should be enough? We chose to look at different kinds of interfaces and different uses of animation, favoring unique examples over cumulative examples, so that we could attempt to have at least one example in as many of model's matrix cells as possible. We rapidly figured out that we would be unlikely to find examples for all the cells. After all, many of the cells represent poorly appropriate use of animation, so to the extent that designers of animation-based user interfaces developed reasonably appropriate interfaces, we should expect to have many cells unfilled. However, with the large but still limited number of examples we surveyed, we cannot be sure if a cell is empty because it represents a poor combination of animation type and communicative function, or if we just did not run across an existing example of a good combination.

A second limitation involves the categories of animation types and communicative functions. As we discussed in Section 3, we refined and modified these categories as our research progressed and the model matured. This suggests that, although useful for present purposes, the categories might be further refined or extended. Indeed, we are presently considering whether to add *transparency* and *entrance/exit* as animation types.

A third limitation arises from our methodology for constructing the model. We used a qualitative approach because our survey sought breadth of examples rather than quantity of examples. It might conceivably be possible, given much more time and human resources, to conduct a sort of random sample of interfaces, and then to produce quantitative results, where the number of examples in each cell of the model's matrix would indicate the appropriateness of the [animation, communication] pair. However, the problems with this sort of quantitative approach look insurmountable. How would we determine the population of interfaces to sample? Should we weight this by use? Should we look at every animation in the sampled interfaces? If so, this might (a) give too much weight to more extensive interfaces and (b) produce misleading indicators of appropriateness where a particular combination is used repeatedly but ineffectually. With the methodology we used, we tried to avoid the problem of examples of inappropriate combinations indicating apparent value, largely by applying our own judgment, based on traditional Norman-like cognitive models of human-computer interaction, to the examples we surveyed. But this approach necessarily involves the subjectivity of the researchers' judgments.

If additional resources were available, clearly would have been better to be able to survey many more interfaces. But from the examples we examined, we were able to construct the model, so we feel it is fair to say that it is possible to build a model that relates the key communicative functions of animation in user interfaces to the nature of the animation. The model is likely valid at least for the functions, features, and relationships disclosed in our survey.

Given these limitations, we suggest that future work on this topic should focus on enlarging the fund of examples in the survey, fostering discussion in the research and practice communities on the categories of animation type and communicative functions, and leveraging this discussion to extend the qualitative analysis from which the values in the model were determined. In particular, we look forward to reports from practitioners on the model's usefulness and validity.

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## 7. REFERENCES

[1] Android (2011). Developer's guide. Available at http://developer.android.com/guide/index.html.

[2] Apple Inc. (2010). Core animation programming guide. Available at http://developer.apple.com/library/mac/#documentation/Cocoa/Conceptual/CoreAnimation_guide/Introduction/Introduction.html#//apple_ref/doc/uid/TP40004627-SW1.

[3] Apple Inc. (2010). Apple human interface guidelines. Available at http://developer.apple.com/library/mac/#documentation/UserExperience/Conceptual/AppleHIGuidelines/XHIGIntro/XHIGIntro.html.

[4] Bumptop.com (undated). BumpTop 3D Desktop Prototype, available at http://www.youtube.com/watch?v=M0ODskdEPnQ.

[5] Chang, B.-W., and Ungar, D. (1995). Animation: From cartoons to the user interface, *Proceedings of the 6th annual ACM symposium on User Interface Software and Technology (UIST '93)*, 45-55.

[6] Chatty, S. (1992). Defining the behaviour of animated interfaces. *Proceedings of the IFIP conference on Engineering Human-Computer Interfaces (EHCI '92)*, 95-11.

[7] Compiz (undated). Compiz Fusion. Available at http://www.compiz.org/.

[8] Hong, W., Thong, J.Y.L., and Cheung, Y.M. (1997), The impact of animation characteristics and task conditions on online user behavior, *Proceedings. of the First China Summer Workshop on Information Management*, 7-11

[9] Hudson, S.E., and Stasko, J.T. (1993). Animation support in a user interface toolkit: flexible, robust, and reusable abstractions, *Proceedings of the 6th annual ACM symposium on User interface software and technology (UIST '93*, 57-67.

[10] Kang H., Plaisant C., and Shneiderman B. (2003). New approaches to help users get started with visual interfaces: Multi-layered interfaces and integrated initial guidance, *Proceedings of the Digital Government Research Conference*, 141–146.

[11] Lang, K. (undated). 'Stand Up' Mac Dock Mockup, available at http://vimeo.com/6695160.

[12] Lang, K. (undated). Smart Inspector — a mockup of a dynamic Inspector Palette, available at http://vimeo.com/8109356.

[13] Maloney, J.H., and Smith, R. (1995). Directness and liveness in the morphic user interface construction environment, *Proceedings of the 8th annual ACM symposium on User Interface Software and Technology (UIST '95)*, 21-28.

[14] Microsoft (undated). Microsoft Future Vision : Healthcare, available at http://www.youtube.com/watch?v=V35Kv6-ZNGA.

[15] Microsoft (undated). Microsoft's Future Vision 2019. Available at http://www.youtube.com/watch?v=g9JBSEBu2q8.

[16] Microsoft (updated). Animations and Transitions. Available at http://msdn.microsoft.com/en-us/library/aa511285.aspx#patterns.

[17] Nielsen, J. (2005). Top ten Web design mistakes of 2005. Available at http://www.useit.com/alertbox/designmistakes.html.

[18] Norman, D.A. (1998). *The design of everyday things*. Cambridge, MA: The MIT Press.

[19] Pattern Factory Oy (Ltd.) (2011). Patternry.com. Available at http://patternry.com.

[20] Pawan, V. (2009). *Web application design patterns*, Morgan Kaufmann.

[21] Plaisant, C., and Shneiderman, B. (2005). Show me! Guidelines for producing recorded demonstrations, *Proceedings of the 2005 IEEE Symposium on Visual Languages and Human-Centric Computing* (VL/HCC'05), 171-178.

[22] Thomas, B.H., and Calder, P. (2001). Applying cartoon animation techniques to graphical user interfaces, *ACM Transactions on Computer-Human Interaction*, 8: 198–222.

[23] Tidwell, J. (2011). *Designing interfaces* (2nd edition), O'Reilly Media.

[24] Toxboe, A. (2011). User interface design patterns Available at http://ui-patterns.com.

[25] Vodislav, D. (1997). A visual programming model for user interface animation, *IEEE Symposium on Visual Languages*, 344-351.