Animations 25 Years Later: New Roles and Opportunities — Source link

Fanny Chevalier, Nathalie Henry Riche, Catherine Plaisant, Amira Chalbi ...+1 more authors

Institutions: Microsoft, University of Maryland, College Park, École nationale de l'aviation civile

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Fanny Chevalier[1], Nathalie Henry Riche[2], Catherine Plaisant[3], Amira Chalbi[1], Christophe Hurter[4]
[1] Inria [2] Microsoft Research [3] HCIL, University of Maryland [4] ENAC
{fanny.chevalier, amira.chalbi}@inria.fr nath@microsoft.com plaisant@cs.umd.edu christophe.hurter@enac.fr

ABSTRACT
Animations are commonplace in today's user interfaces. From bouncing icons that catch attention, to transitions helping with orientation, to tutorials, animations can serve numerous purposes. We revisit Baecker and Small's pioneering work *Animation at the Interface,* 25 years later. We reviewed academic publications and commercial systems, and interviewed 20 professionals of various backgrounds. Our insights led to an expanded set of roles played by animation in interfaces today for keeping in context, teaching, improving user experience, data encoding and visual discourse. We illustrate each role with examples from practice and research, discuss evaluation methods and point to opportunities for future research. This expanded description of roles aims at inspiring the HCI research community to find novel uses of animation, guide them towards evaluation and spark further research.

CCS Concept
Human-centered computing. Visualization. Visualization theory, concepts and paradigms.

Keywords
Animation; transition; taxonomy; roles;

1. INTRODUCTION
Animations are now used extensively in user interfaces. Users might see an animation when they turn on their phones, cueing how to unlock them. Smooth animations help users navigate maps, or give hints about what happened to a window application when it is being minimized. Twenty-five years ago, Baecker and Small's taxonomy of animation [2] shed light on different roles animation could play in user interfaces. In this seminal paper, they went beyond the early use of animation to illustrate processes and algorithms [3], and exposed the fundamental idea that animation can help make interfaces more understandable. Their paper described a set of scenarios—mostly hypothetical—illustrating that animations could help users track objects of interest, choose what to do and see how to do it, but also get feedback on what just happened, or see summaries of what happened in the past.

To the best of our knowledge, Baecker and Small's taxonomy remains the most recent general classification of the *roles* of animations in interfaces — later work introduced new roles with a specific focus on information visualization [4], or reviewed animation methods (in contrast to the purpose they serve) [20][25]. In this paper, we revisit the original classification in light of 25 years of work in HCI in academia and in industry. Our goal is to highlight the growing opportunities for the use of animation, and encourage researchers to evaluate still overlooked aspects of animation. A common language about the roles of animation will foster renewed discussions about animation, and in turn encourage a broader scope of empirical research assessing their merits and limitations. For example, we now include the use of animation to engage, persuade or even fight boredom, commonly used in practice but rarely studied in the literature. Such roles will need to be investigated in more depth as research on storytelling [28][30] and visualization literacy [10] advances.

The contributions of this paper are *i)* a taxonomy of 23 roles, organized in 5 categories, refining and expanding Baecker and Small's work, illustrated by examples borrowed from academic sources and our observations in the wild; *ii)* a discussion of general evaluation methods adapted to each category; and *iii)* opportunities for future research. Like all taxonomies, it attempts to be complete yet simple, and could be further refined. Early evaluation of its coverage and its usability as a common discussion ground was conducted using informal interviews with 20 experts.

2. THE 23 ROLES OF ANIMATION IN VISUAL INTERFACES
We use the broad definition of animation by Betrancourt and Tversky [7]: "*computer animation refers to any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user.*" We chose this definition as it captures the essence of animation as a technique, while not specifying what the animation is supposed to convey. It also embeds both passive and active use.

2.1 Methodology
Our methodology to identify the 23 roles of animation in interfaces, consisted of a multi-step process as follows:

Review – We first searched for related taxonomies (summarized toward the end of the paper). Then, we surveyed animation examples we were most familiar with, i.e. in the domain of information visualization (e.g., reviewing Bartram [4] useful and extensive list of visualization examples, up to 1997). We broadened our search with a literature review of animation techniques in HCI and information visualization by searching on the ACM Digital Library and the website keyvis.org for papers containing the words "animation" or "animated transition" in the list of authors' keywords. We also collected interactive examples that comply with Bertancourt and Tversky's definition that we encountered in websites, mobile apps, and other commercial products.

Build and iterate – We derived an initial taxonomy by grouping animation techniques into roles, and discussing among the authors how these roles differ and how to group them in higher-level categories. We systematically compared what we found with the scenarios proposed by the original Baecker and Small's review to guarantee an all-inclusive correspondence, and considered additional examples to see how they would fit in the taxonomy. This whole process helped us refine: we removed minor roles (very few instances) and hybrid roles (covering two or more existing roles — we illustrate some of these hybrid roles in the discussion), and better fleshed out the remaining ones.

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Validate – We also validated and fine-tuned our final list of roles based on insights gained from interviewing 20 practitioners and researchers of various backgrounds. We conducted informal interviews where we asked these professionals to think of at least five examples of animation use, without further guidance since we did not want to bias their answers. Only once they completed this list, we asked them to familiarize themselves with our taxonomy, and try to identify the roles for each of the examples they provided. We also invited the interviewees to provide feedback on our list and suggest missing roles, if any.

Throughout the entire process, we reviewed metrics and evaluation methodologies used, from HCI, design, psychology and humanities practice. While most traditional evaluation methods can be applied to most roles (e.g. usability testing, controlled studies, satisfaction questionnaires) we suggest specific metrics or methodologies when appropriate. Our goal is to highlight the importance of evaluation, and encourage "role-aware" empirical research. We opted not to report on the results of published evaluations, because mixed results and complex procedures require substantially more space that is available, and we could not provide accurate and nuanced summaries.

2.2 Taxonomy of Animation Roles

In this section, we review all the roles, organized in 5 categories (Table 1). For each role we provide a short definition along with representative examples. We further comment on appropriate evaluation methods and highlight research opportunities for each category. A subset of the animations we surveyed is available at http://fannychevalier.net/animations, a companion website to this paper for the reader to experience the animations we refer to.

Table 1. Taxonomy of roles by category.
✓marks roles present in Baecker and Small's [2] taxonomy.
✪ marks roles with the most research opportunities.

Categories	Roles
KEEPING IN CONTEXT	1. Staying oriented during navigation 2. Supporting tracking during layout changes ✓ 3. Maintaining up to date 4. Replaying history, summarizing ✓✪
TEACHING AID	5. Affordance and preview ✓✪ 6. Training, demonstration by example ✓ 7. Explaining how a system works 8. Illustrating an algorithm ✓✪ 9. Teaching a new representation of information
USER EXPERIENCE	10. Hooking the user ✪ 11. Keeping the user engaged ✪ 12. Providing visual comfort and aesthetics ✪ 13. Making activity and progress visible ✓ 14. Revealing/Hiding Content 15. Providing a virtual tour 16. Providing feedback of input mechanism
DATA ENCODING	17. Revealing data relationships ✪ 18. Conveying uncertainty or randomness 19. Encoding emotion 20. Encoding object attribute ✪
VISUAL DISCOURSE	21. Supporting a narrative ✪ 22. Highlight content 23. Persuading and convincing ✪

2.2.1 *Keeping in Context*

One of the most used roles of animation is to keep users aware of the system's state, as well as keep them oriented in the information space during changes and manipulations. We include four roles in this category:

Role 1: Staying oriented during navigation

Definition – Navigating from an initial point to a target point in an information space (by which we mean a location, or a particular view), was traditionally accomplished by suddenly jumping to the end point. Animation is now commonly used to make navigation feel smooth instead of jarring.

Illustration – After typing "Paris, France" in the *Google Maps* search box, an animation is used to smoothly zoom and pan the map as if flying over the Earth to see the area around Paris. Such type of animation is a cornerstone component of Zoomable User Interfaces (ZUIs) [6]. When the information space is more complex to navigate—as when users need to navigate from one branch of a large organization chart to another—a staged animation breaks down the animation into multiple steps: e.g. SpaceTree [36] 1) shrinks the branches that get in the way of the new layout; 2) re-centers the trimmed tree so that the new branch fits on the screen, and 3) grows the branch out of the new focus point.

Role 2: Supporting tracking during layout change

When the layout of a display changes, it is important that users understand what happens to objects of interest.

Lavoisier's maxim stating that, in real life, "*Nothing is lost, nothing is created, everything is transformed*" has been reappropriated and applied to UI design to improve understandability while navigating and interacting. For example, a window progressively shrinks into an icon in the taskbar after minimization while other taskbar's elements move to make room for it. Tracking of elements whose aspect greatly varies over time may result in intricate animations, as is the case in Gliimpse [15] that smoothly animates between markup source code (e.g. LaTeX or wiki) and the rendered document. With Gliimpse, users see plain text morph into formatted text in the specified fonts or colors, and markup instructions for an image insertion morph into the image itself.

Role 3: Maintaining up to date

Dynamic systems have a constant activity, and may prompt the user of the changes in real time or sporadically by animating objects on the screen to keep her up to date about situations.

A simple example is a clock whose minute hand moves to show the current time. Monitoring applications, such as PlanePlotter [45] that visualizes air traffic in real time, also use animation to reflect the up to date data. Animation is also used as a notification mechanism, to keep the user aware of updates from applications that are not currently visible on the screen: for instance, Moticons [5] are moving icons on the periphery of the display that signal new activity of an application, e.g. a mailbox icon that bounces when a new message arrives. Dyck et al. [16] describe how games use animations for "calm notification" of events, as, e.g., in Warcraft III, notifications of new achievements appear and fade away, while animated red concentric circles and arrows point users to the location of an event taking place.

Figure 1 – Illustration of (a) *Role 1*: ZUIs support infinite pan and zoom in an information space with animation; (b) *Role 2*: Gliimpse [15] animates between markup code (i.e., HTML) and the rendered document.

Role 4: Replaying history, summarizing

Animation is commonly used to replay history of events that occurred in a dynamic system, to reduce change blindness, or to allow the user to go back in time.

Diffamation [11] helps a viewer track how a document has evolved over time. It uses smooth transitions to show added text appearing slowly. Similarly, text that was removed progressively shrinks until it disappears fully. The remaining of the text, corresponding to content that did not change between two versions of the document, moves in trajectories that preserve the visual document structure while minimizing the visual flow. Mnemonic Rendering [8] uses animation to "flashback" what happened to pixels while not being visible in the screen, because they were occluded by another window or in a minimized window; or when the viewer was looking away. The history of pixels is recorded for the whole time they remain hidden or unseen. Once in the field of view again, a "fast-forward" animation unfolds this history until pixels' color reflect the current state.

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We now highlight specific evaluation methods and research opportunities relevant to the four "Keeping in context" roles:

Evaluation: To evaluate navigation support, controlled experiments using revisitation tasks are useful to capture if users know where they are in the information space, and how fast they can return to where they have been before. To measure how animations support keeping track of changes, controlled experiments with motion object tracking (MOT) tasks can point at a set of objects before the animation, and ask users to locate these objects at the end of the animation. These types of experiments generally compare the animation condition to a static control condition. Studies on maintaining up to date and replaying histories can capture how many insights users perceived, or focus on errors being made during information recall.

Qualitative studies—e.g. asking users to describe what happened to target objects in real scenarios—will also provide important insights. Subjective satisfaction questionnaires can capture possible drawbacks (dizziness, distraction, boredom, etc.).

Opportunities: Future research in this space will help uncover the importance of different factors of these animations (speed, number of stages, their order, number of object possibly tracked, etc). Leveraging animations to replay history and summarize insights is perhaps the most under-explored role in this section. However, it proves rather compelling for collaborative applications used over a long period of time (e.g. in visual analytics to describe insight provenance). Revisitation and MOT tasks are most often used in a target-agnostic context (e.g. without visually highlighting objects of interests), which may not be representative of reality, so evaluations of the role and true value of animations in more realistic scenarios is needed.

2.2.2 Teaching Aid

Animation can be used to foster discovery and learning. Educative animations are widespread, in all domains, and for all ages. We list five roles in this category:

Role 5. Providing affordance and preview

Animation can be used to attract users' attention to widgets or methods that may otherwise be hard to discover or understand. Appropriate graphic design might reveal the affordance of a widget and its functionality, but animation can make it more noticeable and better explain how to use it, or offer a preview of what the tool can do.

Some mobile phones use animation to prompt users to perform a sliding gesture to unlock the device. A website might use an animated arrow at the bottom of the screen to encourage users to scroll when nothing else encourages them to do so. Google Sketchup's instructor [45] and proxemics interaction [41] both provide contextual assistance by featuring a preview of a tool in use or a gesture to perform in a short looping animation. While demonstrating what a tool can do (Sketchup's instructor), or how to select a new tool (proxemics), the contextual aids do not, however, provide guidance on how to use the to to make it works (see the next role on *Training, demonstration by example*).

Role 6. Training, demonstration by example

Animations are commonly used as tutorials of how to complete a task through demonstration by example.

GestureBar [44] demonstrates the gesture which can be performed to activate a function, for example demonstrating a rubbing gesture when users put their curser on the eraser icon. Unlike examples in the previous role (i.e. Google Sketchup's instructor and proxemics interaction), the contextual aid of GestureBar consists in demonstrating how to use the tool, rather than giving a preview of what it can do. ToolClips [21] adds short narrated demonstrations to the traditional text descriptions of tooltips. JugglingLab [45] allows users to author juggling patterns by specifying a "score sheet", and watch the resulting animation of a stickman juggling colored balls.

Role 7. Explaining how a system works

Animations are often used in educative applications and media to explain how a system works.

Examples of animation that explains various phenomena and complex systems can be found in abundance, e.g. they can explain how the heart works by showing ventricular beats driving and regulating blood flow, or how a mechanical watch works [45] to depict how energy is transferred from the barrel to the wheels and to the clock hands. These educative dynamic illustrations are often integrated within a larger communication medium for storytelling (see 2.2.5 Visual Discourse).

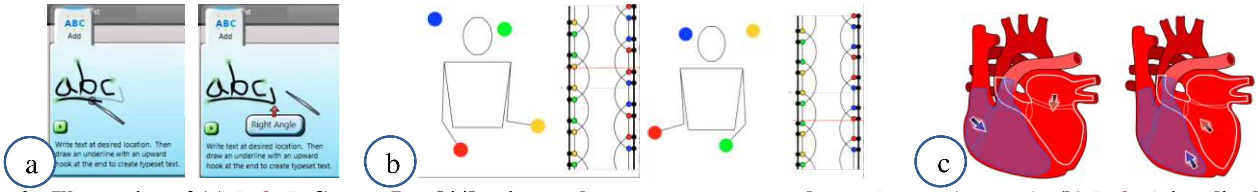

Figure 2 - Illustration of (a) ***Role 5*****: GestureBar [44] animates how to use gesture tools –** © A. Bragdon, et al.**; (b)** ***Role 6:*** **jugglingLab [45] animates a sequence of a juggling pattern –** © J. Boyce**; (c)** ***Role 7:*** **educative animation using bouncing arrows to illustrate blood flow in the heart –** *adapted from "Exploring the Heart" by Aboutkidshealth (Youtube).*

Role 8: Illustrating an algorithm

Animation can be used to illustrate a mathematically defined simulation, or an algorithm.

One of the pioneer use of animations described by Baecker in 1990, was to explain how an algorithm works. Sorting out Sorting [3], shows how elements to be sorted are progressively rearranged by different sorting algorithms. The website of Setosa [45] uses a series of animations to explain the logics of various mathematical concepts. For instance, to explain Markov chains, a ball travels through a graph representation of the chain, from node to node on the chain, conveying how decisions are made to choose which edge to follow based on probabilities associated with the edges.

Role 9: Teaching a new representation of information

Animation can be used to help users learn a novel spatial layout or a new visual encoding altogether by demonstrating how items are transformed (grouped, aggregated or divided, change visual properties), and moved to their final location.

Animation is used in Twinlist [35], to help physicians compare two separate lists of medications. Animation is used to teach users how the items in the two lists are reorganized and merged based on similarities and difference, therefore explaining a new unfamiliar layout. Animation is also used in NodeTrix [27] to explain how matrix representations of graphs correspond to the more familiar node-link diagrams. Once learning has taken place, the animation may not be needed anymore and its use discontinued.

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Evaluation: To evaluate teaching aids, a common study design is to compare conditions with and without animations, using a between-subject design (where one group sees the animation and the other one not) [40]. These studies often administrate pre-test (to capture pre-existing knowledge) and post-test, featuring comprehension questions. Questionnaires can measure subjective ratings about the perceived value of the animation. For affordance and demonstration by example, user studies can verify that animations improve discoverability of a feature and/or its execution, and see if new knowledge persists over time [43].

Opportunities: Because the outcomes of existing empirical studies are mixed, more research to evaluate the value of animation as teaching aid is needed [40]. Understanding when to use the technique, what are the important components and how to streamline the authoring of effective animations are still open questions. Affordances and teaching by demonstrations remain important roles as the HCI field strives to make interfaces more "natural" [31]. When menus and buttons with labels are not present, discoverability of what is possible becomes an issue for new users [14]. Research exploring how animation can be complemented by other modalities, such as narration [33] or interactivity [32] for education is also a promising direction. Evaluating the value of interactive animated material such as Introduction to Machine Learning [45] and research on authoring tools to facilitate the generation of such material are other opportunities for the field.

2.2.3 User Experience

Animation is often described as visually pleasant, playful and engaging, all qualities that improve the user's experience when interacting with a system. Animation is now considered a core component of UI design. In Google Android's Material Design principles for instance, "*authentic motion*" is defined to "*describe spatial relationships, functionality, and intention with beauty and fluidity*". The Windows UX design guidelines state that "*purposeful, well-designed animations bring apps to life and make the experience feel crafted and polished […] The quality of the experience depends on how well the app responds to the user, and what kind of personality the UI communicates.*" We find five roles for animation as a tool to enhance user experience:

Role 10: Hooking the user

Animated introductions can make a website or application attractive and memorable, possibly "hooking" users and encouraging them to explore further.

Websites often use animation for fun, to appeal or intrigue users, resulting in an amusing, playful, enjoyable experience raising their interest. For example, the Christmas express website [45] starts with a man pedaling on a bike, then opens a full landscape of turning wheels and falling snowflakes and music. The mobile application Soundhound [45] displays radiating bubbles of changing colors while waiting for users to start recording sound.

Role 11: Keeping the user engaged

Because animations attract a viewer's attention, it can be used to keep user engaged (or get their attention back) when an activity require a substantial attention time.

Video games such as HayDay [45] or student testing environments can leverage animations to keep users engaged in the game, or as a reward mechanism after a substantial effort or lengthy problem. This role is also important in presentations and report tools such as PowerPoint, which contains animations that authors can insert to retain the attention of the audience, or re-engage it. This role is most useful when content is lengthy and the audience is passive. For example, many data-driven videos [1] and documentaries contain animated charts in addition to the voice narration, in the hope that viewers will watch the materials till the end.

Role 12: Providing visual comfort and aesthetics

Animation allows for smooth transitions, which can be experienced as more visually comfortable than jarring, abrupt transitions. When properly done, animations can also have true aesthetics qualities.

Examples abound: icons explode into windows, product cards flip to show more details as if on the back of a card, or pixels fly like particles blown by the wind as found in Histomages [13]. Markus Ekert, a motion designer, used animation to simulate a curtain effect revealing content under the main window of a touch mobile phone [45]. Metaphors of the real physical world are often used,

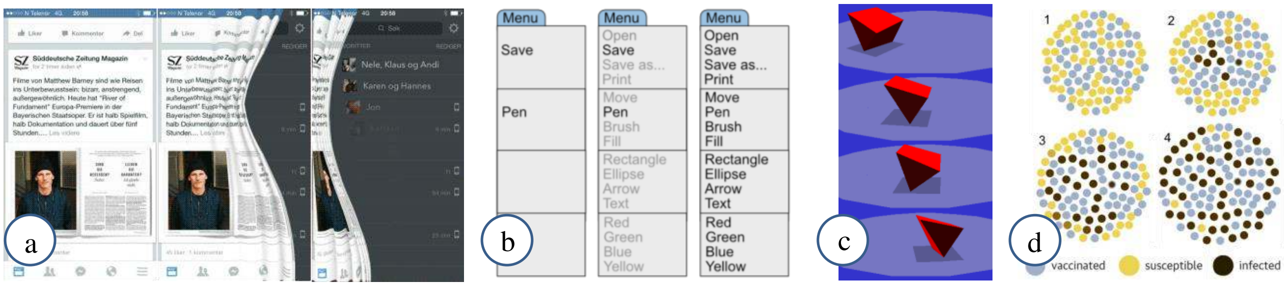

Figure 3 - Illustration of (a) ***Role 12*****: animation is used to simulate a curtain effect when sliding a window to reveal underneath content on a mobile phone –** © M. Ekert**; (b)** ***Role 14*****: ephemeral adaptation progressively reveals content in menus based on history –** Adapted from [19]**; (c)** ***Role 19*****: Polly is a walking prism whose motion conveys a mood –** © K. Perlin**; (d)** ***Role 23*** **: animation shows how flu spreads in a population of vaccinated (blue) and vulnerable (yellow) children –** Adapted from The Guardian**.**

gered animations, which consist of introducing a small delay in the motion start time of elements, aim to recreate the feel of ballet choreography [12].

Role 13: Making activity visible

Animation is used as a visual feedback to track progress, and a distractor to fight boredom when the system is busy.

Since the hourglass cursor introduced in Windows 1.0 (1985) and NeXTSTEP's spinning wait wheel (1989), animated icons have been used in place of the cursor to indicate that the system is busy working (presumably) on an operation. Progress bars show the remaining time, or percentage of completion before the process is completed. The escriba website [45], for example, uses fun animations to keep users entertained while waiting. Countdowns are used to prepare the user of an imminent event, e.g. when PhotoBooth is about to snap a picture.

Role 14: Revealing/hiding content

Content may not be visible at all times, but made visible through hovering or clicking, and animations are used to reveal or hide content in a transient manner.

Examples include side panels swooshing from the edge of mobile device screens, Drop-down menus that expand smoothly on desktop applications or balloon tooltips that appear progressively when the cursor hovers over icons. Ephemeral adaptation [19] is an advanced technique that relies on prediction to progressively reveal features in an interface: predicted items appear immediately, while remaining items gradually fade in.

Role 15: Providing a virtual tour

Animation can help users experience a phenomena from the physical world and experiment with alternatives

When architects work on a building, animations of the virtual world [18] can provide a tour of the building and show how they are integrated in the landscape. Users shopping for a new car can experience in the driver seat in various situations. While this can be achieved with still pictures, the dynamic experience is more realistic and visceral with animated tours. Similarly, complex molecules can be observed from different angles, and travel through the galaxy simulated (i.e., World Wide Telescope [45].)

Role 16: Providing feedback of input mechanism

Animation can be tightly coupled with direct user input, to convey a particular input metaphor, the state of the input device, or the state the device sensors.

Performing a slide or swipe gesture on a long document on a tablet triggers the auto scroll of the document, whose speed progressively decreases (simulating friction) until the document stops moving. Parallax effects, often seen in phones, respond to the orientation of the input device, captured by accelerometers. Touch devices sometimes also use a ripple animation to confirm input.

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Evaluation: To evaluate impact on user experience studies can measure viewing time, dropout rates, interactions at the first encounter, during or immediately after the animation, using click log or tracking mouse and eye movement. A/B testing facilitates incremental improvements. More qualitative studies are required for assessing visual comfort and aesthetics, or evaluating virtual tours or making background activities visible. Questionnaires [24] and interviews help tease apart subjective impressions and identify possible causes of problems.

Opportunities: Aesthetics is an extremely challenging and overlooked topic in HCI. Research on how to improve quality and better evaluation methodologies will be instrumental in moving the field forward. Studies assessing first impressions of infographics [23] might provide some inspiration. Collaborative research with web and graphic design practitioners is needed.

2.2.4 Data Encoding

Information visualization encodes data attributes with visual variables such as position, color, size or shape. In dynamic visualizations, variables may change over time, reflecting changes of the underlying data attributes. Visual variables are not necessarily static: motion can also be used to encode a data attribute. Animation, as a means to encode data characteristics, can be broken down into four roles as follows:

Role 17: Revealing data relationships

Animation is commonly used to show how data changes and evolves over time, but also over other non-temporal dimensions such as age or income.

A famous example is Gapminder [45]. Countries are placed on a scatterplot based on their birth rate and life expectancy statistics, and animation reveals how the world has changed over two centuries. Users can simply play the animation or control the advance step by step and see the circles for each country move over time. Trails can be left behind the data points. Cartographic applications are another example, e.g. to show how rainfall location affects forest growth [9], illustrating how causality is a data relationships that animation is often used to convey [42].

Role 18: Conveying uncertainty or randomness

Animation is used to represent randomness or uncertainty by moving objects on the screen in a random way over the range of possible values.

In [22], cancer risk was first represented as a fixed array of 100 icons, with a number of them dark (e.g. 9 for a 9% chance), but some users wrongly interpreted the display and believed that they have a 0% or 100% chance of developing cancer. Animation was then used to enhance the representation of randomness by changing the position of the dark icons every 2 seconds. Similarly, animation has been used to indicate uncertainty by wiggling the position of points or boundaries on maps or other visualizations.

Role 19: Encoding emotions

Particular motions can be used to convey stereotypic emotions.

The fact that motion is a good proxy for emotion has been known for long in traditional cartoon animation: *"When you take something that's inert, and through motion, give it life, make it appear to be alive, living, breathing thinking and having emotions, that's animation."* [29]. Perlin has explored different emotion expressions with Polly, a prism that walks around a surface. Different behaviors, like feeling dejected, can be assigned, which affects the prism's gait [45]. This small application very nicely illustrates how motion can affect perceived emotion. Yet, it is just a prism!

Role 20: Encoding object attribute

Motion can be used to encode different attributes of visual objects, in particular, different categories. It can then be used for filtering and brushing [5].

When reordering a priority traffic list with Mobilistes [39], list items are moved using an animated trajectory that is specific to the type of mode of transportation (bus, car or plane). In motion pointing [17], each visual item of the interface such as a push-button or radio-button has a driver—i.e. an animated point displayed on top of it and playing a unique cyclic elliptical movement. To select a specific item, the user has to imitate the motion of its driver using the input device and mimicking that motion (i.e., shape of trajectory, frequency, phase, amplitude, etc.)

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Evaluation: Controlled user studies can evaluate how well users perceive the data encoded by the objects' motion. Subjective metrics can be used to evaluate the impact of such encodings. In [22] participants were presented with cancer risk estimates using representations varying in how the randomness is expressed, then asked to rate their perceived cancer risk, level of uncertainty, and worry. Questionnaires can also investigate social perceptions, asking participants to describe impressions and positive/negative sentiments generated by the animated objects.

Opportunities: While techniques such as Gapminder are popular, the value of animated displays compared to static one (such as small multiples) is still unclear [37]. In fact, because of its strong perceptual draw [4], animation might prevent users from perceiving other elements of the display. However, it also offers unique opportunities to encode complex and subjective information such as convey musical impressions or human moods and feelings.

2.2.5 Visual Discourse

Animation is a common tool for storytelling and visual discourse, hence the abundance of examples. We identified four roles of animations for discourse purpose, as follows:

Role 21: Supporting a narrative

Animation supports narrative by providing progressive disclosure of arguments and transition smoothly between them [38].

Pitch interactive recently published a powerful online narrative visualization documenting every drone strike carried out in Pakistan [45]. Animation is first used to introduce the topic and progressively disclose the elements of the display. Then, the series of drone attacks periods is interspersed with pauses and commentaries. It includes clickable links where animation is used to transition from current display to the next. Scrolling is also commonly used to activate a transition to a next step of the story e.g. in "How the Recession Reshaped the Economy, in 255 Charts" [45]—New York Times. "Fallen of World War II" [45] is an interactive documentary that examines the human cost of WWII. The animation follows a linear narration, but it allows viewers to pause during key moments to interact with the charts and explore further.

Role 22: Highlighting content

Motion has a strong attention-drawing power, and can be used to highlight or emphasize content.

For example, an animation making a set of bar in a chart jump when the narrator is discussing them is used in the data video depicting wealth inequality in America [45]. Animation featuring icons moving along a line chart can also serve to emphasize an increasing or decreasing trend. Animation of objects or text blinking, jumping or getting larger is also commonly featured in presentation tools such as PowerPoint to emphasize a point.

Role 23: Persuading, convincing

Animation can be used to make a particular point across with the intent to persuade or convince its viewer.

The Guardian published a story aimed at convincing people to vaccinating their children by illustrating how disease spreads on hypothetical populations of children whether they are vaccinated or not. An infected person regularly shows up and enters in contact with a child: a red circle flies over and bumps into a child who may or may not contract the disease. A vulnerable child will automatically turn red at the contact of the red circle, and the flu will spread to all surrounding vulnerable children. Different populations show the impact of vaccination rates conveying that immunizing a child does not only protect the child, "*immunization is contributing to the control of the disease in the population*" [45].

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Evaluation: Since visual discourse and storytelling are relatively recent style of interfaces in HCI [28], there is limited work on evaluation. Controlled studies comparing versions with and without animations can reveal aspects such as comprehension, attention or engagement, assessing if people changed their behavior by designing specific pre-test and post-test. Memorability could also be a useful metric when dealing with persuasion.

Opportunities: Many parameters come into play such as number of steps in a narrative, the timing, the mapping of the animation with the story content (e.g. semantically relevant choice of pictograms and motions). Much research is needed to study the impact of each design component. Like every other technology animation can be misused to fill a nefarious role. For example, instead of attracting users' attention to a new or important item it can be used to distract (focusing attention on the wrong thing as a strategy). It can be used to imply some magic effect that does not exist, or explain how things work the wrong way. Research on deception [34] is certainly important to inform viewers and prevent designers to (un)intentionally use animation for such purpose.

3. RELATED TAXONOMIES

This paper builds on Baecker and Small's original taxonomy [2]. However, other taxonomies characterizing aspects of animations have been proposed, in particular for visualization. The most related work is Bartram [4], listing potential applications of motion in visualizations. To our knowledge, this technical report is the only attempt after Beacker and Small's to discuss new *roles* of animations, albeit focused on data visualization. The list is comprised of five applications of motion for visualization such as using motion to communicate data relationships or for representing change. Four of these applications fall directly into one of the 23 roles described in our paper. For two of them, dealing with roles for keeping users in context, we expand the scope and provide examples beyond data visualization. The last application proposed in [5] deals with change blindness and ensued perception concerns, which we regard as a consideration rather than a role. Overall, our list of roles integrates and expands upon Beacker and Small's and Bartram's list to offer novel ones.

Another related taxonomy is in Heer and Robertson [25] presenting *transition types* between data graphics in the context of statistical visualizations. They identify seven transitions between data graphics based on operators such as view transformation, filtering or data schema change. Building upon this work, Fisher [20] suggests a taxonomy describing the *types of change* that can occur in visualizations and distinguishes six types of transitions related to data and view transformations. Both taxonomies focus on a single specific role of animation, namely, support the transitioning between different views/states of a system. Both list tasks and situations in which animated transitions may be appropriate, but do not explore the other roles animation can play in GUIs.

Besides the taxonomy of transitions, Fisher [20] discusses the *context* in which the animations are used in visualization, distinguishing between *presentation* (i.e. the data is well known to the presenter and the viewer is passive)—which relates to our teaching and discourse roles; and *data exploration*, where the data is still unknown, but where the viewer has full control over the interactions. While he does not explicitly discuss roles of animations per se, Fisher still stresses that animations can be designed for different purposes (presentation vs. exploration). Finally, a related taxonomy by Heer and Shneiderman is described in [26] for interactive dynamics for visual analysis. It consists of twelve *task types* that can help understand when and why an animation is triggered, but is not explicitly delving on roles of animation.

In summary, there has been many efforts towards classifying and describing how animations are used, especially in data visualization. This paper builds upon several of these efforts and expands on them by providing several novel roles of animation for GUIs in general and pointing towards research opportunities.

4. DISCUSSION AND FUTURE WORK

Like all taxonomies, our list of 23 roles organized in 5 categories attempts to be complete yet simple. Below we outline limitations and suggest areas for further refinement and validation.

4.1 Coverage

Amongst the 5 authors of this paper, we gathered over 200 examples of animation to build and refine our 23 roles. We could assign all of our examples to at least one role in our list. To further assess whether our list was comprehensive, we asked 20 colleagues with different backgrounds (HCI researchers and practitioners such as user experience and interaction designers, UI developers) to provide examples they could think of. Overall, we collected 95 additional examples (accessible on our companion website http://fannychevalier.net/animations). We could fit 98% of these examples within our taxonomy. The remaining (two examples) were thoroughly discussed as they dealt with animations reflecting user input, such as the parallax effect resulting from holding a smartphone at different angles. We initially opted to exclude these effects as they are very tightly coupled with interaction, making it debatable whether we considered them animation. However, since several interviewees included such examples, we added the role 16: "providing feedback of input mechanism", covering our entire corpus.

Our corpus did not cover examples of animation beyond GUIs such as tangible interfaces (e.g. physical visualizations) or augmented reality interfaces. While these examples are beyond the scope of our paper, we believe many of our roles would still be relevant. We hope future work will expand our classification and reveal specific roles of animations to such interfaces.

4.2 Combinations of roles and granularity

Roles listed in the paper are not orthogonal and we encountered many examples where animation fulfilled multiple roles. For example, animations in Histomages [13] and NodeTrix [27] are used during the first encounter of the technique as a teaching aid to help users understand a mapping between a familiar representation (image and node-link diagram respectively) and a new representation of the same information (histogram and matrix). However, once users understand this mapping, the animation can aid them to keep in context, and support the tracking of object during successive layout changes. These animations might also be combined with others focusing on improving the user experience.

We originally had many more roles which we eliminated as they seemed to be either a composite of multiple other roles, or rather application-specific and rarely encountered. For example, "confirming selection" was dropped as a combination of "making activity visible" and "maintaining up to date". While we strived to reach optimal granularity for the roles (e.g. not representing a handful of examples but not representing several hundred either), it still varies substantially. While several roles could certainly be subdivided further, our intent was to provide a reasonable number for practical use and highlight novel ones since Baecker and Small, to inform and inspire future research on animations.

5. CONCLUSION

We proposed to revisit the roles of animation in graphical user interfaces, 25 years after Baecker and Small [2] seminar paper. By reviewing the literature and commercial products, we uncovered several novel roles of animation: to improve user experience, to encode data and support discourse. Our intent with this classification is twofold. We aim at providing practitioners with a comprehensive yet simple taxonomy accompanied by a corpus of examples to inform the design of GUIs and provide initial guidance towards appropriate evaluation metrics. We also want encourage the research community to think more broadly about the roles of animation in interfaces, identify research opportunities in the space, and further investigate how and why roles have evolved and can further evolve. In particular, we wanted to attract attention to a variety of evaluation methodologies (beyond motion object tracking often seen in research papers), and identify roles that are commonly seen in practice but seldom studied in research.

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