Translucent Tangibles on Tabletops: Exploring the Design Space

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Abstract
Tangible user interfaces play an important role in blended interaction concepts. In this paper we explore the design space of tangibles made of translucent materials and how they can be used on interactive displays; we investigate design aspects such as materials, form factors and interaction techniques and review existing translucent tangibles in literature accordingly. We also present three of our prototypes that are currently in development.

Author Keywords
Tangible User Interfaces, Blended Interaction, Interactive Surfaces

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

Introduction
Tangible user interfaces (TUIs) [2] play an important role in realizing blended interaction concepts. They take advantage of our natural motor skills by providing physical affordances and support collaborative work scenarios (e.g., by group awareness) [4]. By controlling digital content directly with tangibles on interactive surfaces, it becomes possible to blend the haptic of

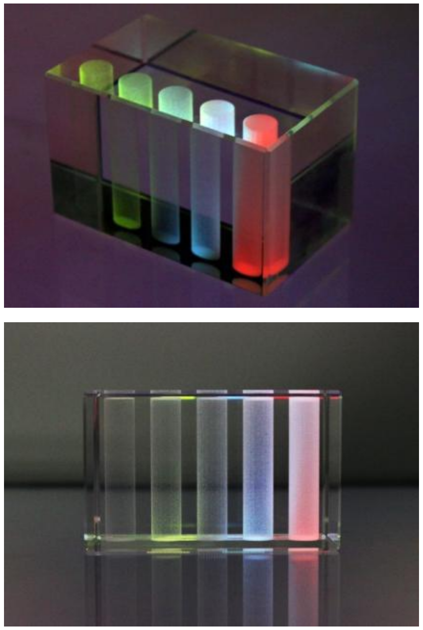

Figure 1 Block made of glass with laser engraved cylinders. It is illuminated with different colors from below by the tabletop. The cylinders were engraved with different densities to investigate the strength of the glow effect (low density left, high density right).

physical real-world objects and the manipulation of virtual data.

In this paper, we focus on tangibles made of translucent materials (which can be either semi-transparent or completely transparent). In our opinion, translucent tangibles on tabletops are a very promising approach to blended interaction. Seeing visualizations through or even inside a physical object (see Figure 1) literally blends virtual data and its graspable representation. In that way, the physical object becomes less obtrusive but manipulating the digital can still be achieved in a tangible way.

Digital content, shown below a transparent tangible instead of around the tangible, occupies less space on the display. This offers possibilities for novel and more compact visual designs. Beyond that, the content can be manipulated through the tangible by touch input. Translucent tangibles can be applied in various applications. Examples reach from tangible lenses to physical ambient notifiers by applying illumination effects. Furthermore, see-through tangibles could be used to create mockups of future (semi-)transparent mobile devices.

In recent years, various research prototypes and systems were developed which apply tangible user interfaces on interactive surfaces. Some of these systems already use (semi-) transparent objects to interact with virtual content (e.g., [2, 9, 12, 13]). Few of them already explicitly leverage the advantages of transparency (e.g. [9]); others use translucent materials only as eye-catcher (e.g. [5]).

In the following, we explore the design space of transparent tangibles, since it has not been fully investigated yet. In particular, we contribute three design aspects of translucent tangibles: materials, form factors and interaction techniques. We discuss how existing systems consider these aspects and which aspects were not considered at all. Furthermore, we report on own experiments with translucent tangibles and present application examples we are currently working on. We conclude by discussing advantages and limitations of transparent tangibles.

Constructing Translucent Tangibles

Various materials can be used for realizing translucent tangibles. In the following we discuss existing approaches and present our own experiments.

Translucent Tangible Objects

Completely transparent objects are usually made of acrylic glass [9, 13] or transparent foils [6, 7]. Other options are tangibles made of silicone or similar elastic materials [10, 13]. Fukuchi et al. [1] applied glass fibers to transmit light from the display to the top side of a tangible. These tangible objects are not completely transparent, but the content underneath becomes visible. Another example for semi-transparent tangibles is the TaPS widget [8]. It applies scattering foil which scatters light depending on the viewing angle. This allows some users seeing content below the tangible, whereas from a different viewing angle the visualization is blurred.

Transparent Visual Markers

One common way to realize TUIs on interactive surfaces is to recognize visual markers by an IR-based tabletop system. The markers (e.g., Microsoft Byte

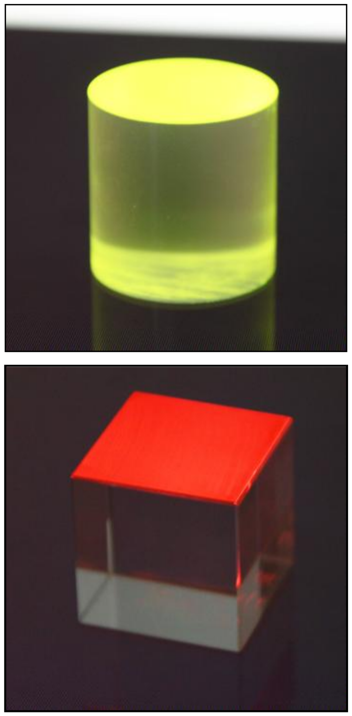

Figure 2 Top: A cylinder made of *Plexiglas Endlighten* illuminated from below with yellow color. Bottom: A glass cube with back projection foil on top illuminated from below with red color.

Tags[1]) are usually printed on paper and attached to the respective tangible. However, this occludes the content visualized underneath, even if the tangible object itself is translucent. To realize completely transparent tangibles, markers can be made of transparent IR reflective foil. In that way, the marker is not perceived by users and allows seeing through the object to the display surface below. For the experiments and prototypes described in this paper, we used a SUR40[2] tabletop which is capable of tracking tags due to the PixelSense technology. For transparent markers we used special sun blocking foil, cut Microsoft Byte Tags out of this material and attached them to translucent objects.

Illuminating Translucent Materials

Although the content underneath a semi-transparent object is not clearly visible, semi-transparent materials can enforce lighting and color effects by illuminating the tangible with light from the display. For that, we ran a series of experiments with different materials. Amongst others, we tested *Plexiglas EndLighten* which is translucent and light diffusing. When a cylinder is illuminated from underneath it starts glowing, mainly on its upper side (see Figure 2 top). A similar result can be achieved by attaching back-projection foil on top of a fully transparent tangible made of glass. In this case the illumination effect is only visible on the top (see Figure 2 bottom). Furthermore, we experimented with laser engravings. Therein, a 3D model is converted to a point cloud and engraved with a laser inside of a glass object (see Figure 1). When illuminated from underneath, the engraved shape (or parts of it) reflects the light and starts glowing. Other parts of the object are not affected by the illumination.

[1] http://msdn.microsoft.com/en-us/library/ee804885/

[2] http://www.microsoft.com/en-us/pixelsense/

Form Factors of Translucent Tangibles

In the following, we classify the form factors of translucent tangibles into basic (*foils*, *plates*, *tokens* and *blocks*) and compound forms. Their main differences are their size (the area occupied on the display) and their height. We explain the characteristics of each form factor and provide examples if and how they were applied in existing systems.

Basic Forms

Foils are very thin and made of bendable material. In comparison to other form factors they are less graspable. Transparent foils were used for example by Kim and Elmqvist [6] and Koike et al. [7]. They applied them for magic lens interfaces such as geo-lenses or graphic filters.

Plates are of similar size as foils. However, they are slightly higher and not bendable, but thus more graspable (Figure 4). However, plates are still thin enough to give users the impression of touching the content underneath through the transparent object. Rectangular transparent plates were applied for DataTiles by Rekimoto et al. [9] and for Tangible Tiles by Waldner et al. [12]. They used plates as containers for data or assigned functions such as magnifying the content underneath. Our review of existing literature revealed that other shapes than rectangular ones were hardly applied up to now.

Tokens are smaller in size than foils and plates, but thicker (Figure 3). Touch interaction on tokens is not feasible anymore due to the occurring parallax effect.

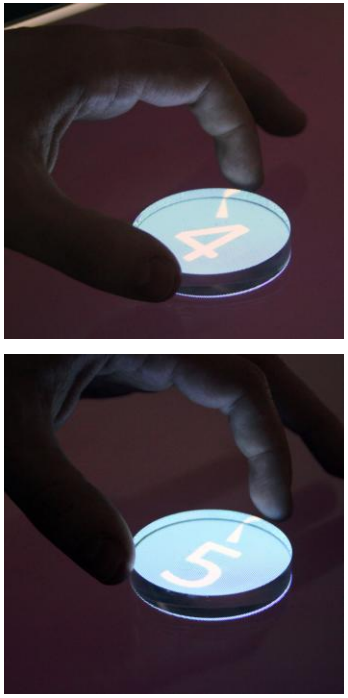

Figure 3: Transparent token for adjusting values. By rotating the token to the right, the value is increased by one. By rotating it to the opposite direction, the value is decreased. The number and rotation indicator is shown below the token, thus saving valuable display space.

Completely transparent tokens were hardly used so far. One exception is the NUIverse application[3]. It applies transparent tokens to invoke menus and to show the current menu level below it. Some systems such as reacTable [5] or Facet-Stream [3] apply translucent tokens as well. However, they are recognized by opaque visual markers. They do not explicitly leverage transparency and are used as eye-catchers only.

Blocks are bigger and thicker objects such as cubes or cylinders (Figure 2). Due to its size, a block has less the affordance of a movable handle but rather that of a fixed positioned object. To our knowledge blocks, explicitly making use of translucency, were not used so far for tangible interaction on tabletops. In our current work we explore the use of blocks for notification purposes.

Compound Forms
Compound forms are combinations of the mentioned basic shapes. Examples for such a combination are some of the SLAP Widgets presented by Weiss et al. [13]. For instance, they realized a slider and a turning knob made of transparent acrylic which can be seen as a combination of *Tokens* and *Plates*.

Each of the mentioned forms can be made of solid or elastic translucent material. The latter can be squeezed and thus, change its form, at least temporally. This was used by the physical keyboard overlay of the SLAP Widgets System [13] and by Sato et al. [10] for a paint application.

[3] http://www.nuiverse.com/

Interaction with Translucent Tangibles

Interaction with translucent tangibles is similar to that of opaque tangibles in their general handling. Besides the common interaction techniques with tangibles (e.g., rotation, bending, flipping) transparency supports additional interaction on and through the object. In the following we will therefore focus on these additional features that extend the existing interaction space of opaque tangibles.

Positioning by translation
As with existing opaque tangibles, it is possible to reposition translucent objects by moving them across the interactive surface. However, due to the transparency, precise positioning becomes possible. Especially with form factors such as foils, plates and tokens, small virtual objects below can be targeted in a precise way which is hard to achieve with opaque tangibles. To further ease precise positioning, visualizations such as crosshairs representing the center of the tangible could be shown. For example, a small crosshair (Figure 4) visualizes the center of the transparent tangible lens.

Stacking
Transparency allows stacking of tangibles, since the visual markers are still recognized by the systems if they are located on top of another thin transparent object (e.g., a foil or plate). In contrast to existing stacking techniques, transparent tangibles allow see through visualization or even interaction through several levels. Due to their transparency, several foils can be laid on top of each other [6] and their tags are still recognized. Our experiments on the SUR40 revealed that for plates with a thickness of 3mm it is

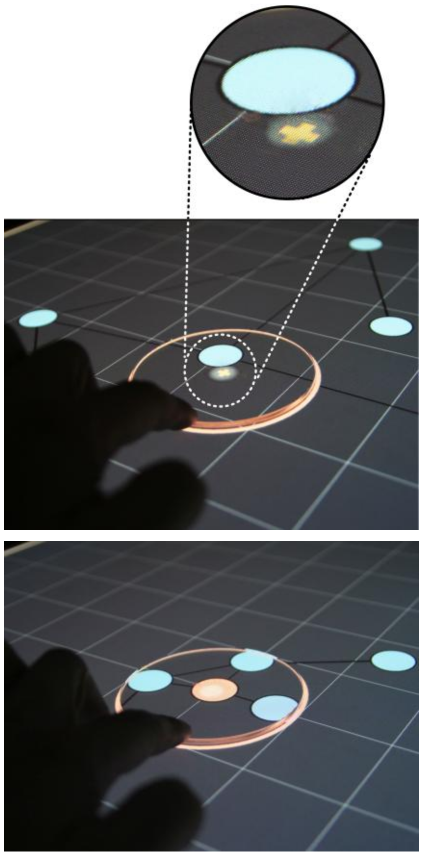

Figure 4 Tangible graph lens: Positioning the plate on a node (top) animates all its neighbors below the lens (bottom). A crosshair is used as a target indicator.

possible to stack at most two on top of each other before tag recognition fails.

Touch Interaction
Foils and plates are defined as being thin enough for touch interaction through the object. This allows direct manipulation of the content below the entire tangible. To our knowledge no other system is capable of that. Furthermore, dragging virtual objects "from" the tangible onto the display and vice versa is possible. For thicker objects (i.e., tokens and blocks) precise recognition and distinction of touches is not reasonable anymore. However, if an object is not thicker than 50mm and its upper side is touched, light is reflected down to the interactive display and recognized by the system. In that way, simple ways of interaction, such as tapping the tangible or holding the hand on it, can be realized.

Application Examples
We currently work on several example applications which allow blended tabletop interaction by making use of translucent tangibles.

Dial Knob
Figure 3 shows a round token for changing property values for an image it is put on (e.g., contrast and brightness). The current value is visualized below the token. Rotating increases and decreases the value shown underneath. In that way it is not visually decoupled from the physical object. We currently investigate further interaction techniques such as stacking or flipping tokens. This can be used to, e.g., adjust values in smaller step sizes. A dial knob could also be used for other value adjustments, e.g., volume or speed of a video sequence.

Tangible Graph Lenses
Foils and plates are promising form factors for tangible lenses. We developed a specific tangible graph lens. It is similar to the virtual "bring neighbors" lens [11]. Moving our lens on top of a node animates all of its neighbors under the lens. In that way connections in large cluttered graphs can be easily explored. A small crosshair in the center of the lens supports targeting and eases the precise positioning of the tangible lens on top of the focused node (Figure 4). Beyond that, it is possible to interact with the nodes by touch input on the physical lens.

Ambient Notifiers
Transparent blocks made of glass and especially those with laser engraved icons can serve as ambient notifiers. They are put on the tabletop and illuminated automatically from underneath, whereby the laser engravings start to glow. For example, if instant messages are received, updates in a social network occur or an error message arises, the object is illuminated or the color of the illumination is changed (e.g., red for alerts). It is also possible to illuminate separate parts of the engraved object or playing animations (blinking or moving the light source). Users can interact with the block by shortly tapping its upper side. As a result, the notification is stopped (or snoozed). Holding the hand on top of the object invokes further information, such as opening the email program or a website.

Discussion and Conclusion
In this paper we explored the design space of translucent tangibles for tabletop interaction. In particular, we analyzed how transparent tangibles were used so far in selected existing systems, with regard to

their materials, form factors and interaction techniques. Furthermore, we contributed the results of our own experiments and presented three novel application examples which explicitly make use of (semi-) transparent materials for TUIs.

Applying translucent tangibles provides a lot of advantages for blended interaction. The transparency makes physical objects less obtrusive and digital data can be still manipulated in a graspable way. By showing virtual content below the transparent tangible, the physical and digital are literally blended. This occupies less space on the display. Furthermore, stacking of objects becomes possible and light effects can be realized by illuminating the tangibles from below.

However, there are also limitations of transparent tangibles. As in all TUIs, the size of the tangible objects is fixed and unchangeable. Hence, the representation of the content visualized below might have to be adapted to its size. Moreover, without the illumination of the tabletop the transparent tangibles do not convey complex visual information. The function of the tangible is communicated through its form or shape only, but not by its color. However, transparency provides a more flexible use, as changing the visualization below allows a dynamic assignment of functions.

For future work we plan to extend our survey of existing systems and to evaluate the use of translucent tangibles for blended interaction.

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