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FugaciousFilm: Exploring Attentive Interaction with Ephemeral Material

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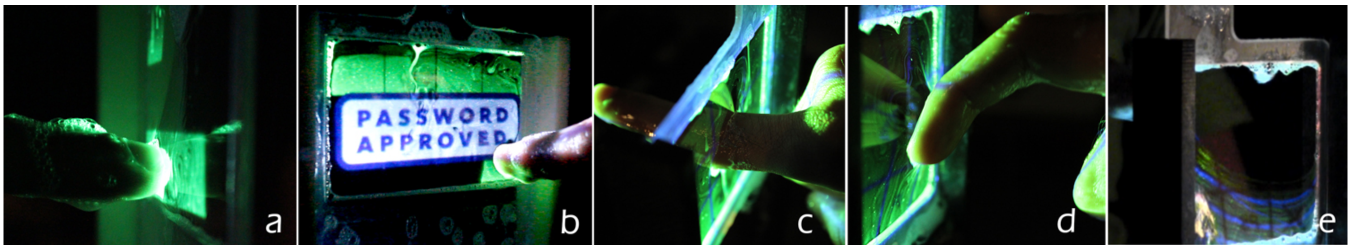

Figure 1. FugaciousFilm demonstrating attentive interactions with an ephemeral material. (a) Touching the soap film surface, (b) entering a passcode by dragging a finger across the film, (c) pushing without bursting the film, (d) hooking a finger when pulling the film, and (e) an instance of the film bursting while playing Tic-Tac-Toe game.

ABSTRACT
This paper introduces FugaciousFilm, a soap film based touch display, as a platform for *Attentive Interaction* that encourages the user to be highly focused throughout the use of the interface. Previous work on ephemeral user interfaces has primarily focused on the development of ambient and peripheral displays. In contrast, FugaciousFilm is an ephemeral display that aims to promote highly attentive interaction. We present the iterative process of developing this interface, spanning technical explorations, prototyping and a user study. We report lessons learnt when designing the interface; ranging from the soap film mixture to the impact of frames and apertures. We then describe developing the touch, push, pull and pop interactions. Our user study shows how FugaciousFilm led to focused and attentive interactions during a tournament of enhanced Tic-Tac-Toe. We then finish by discussing how the principles of vulnerability and delicacy can motivate the design of attentive ephemeral interfaces.

Author Keywords
Ephemeral User Interfaces; Tangible Interaction; Soap film; Attentive Interaction; Non-Ambient Interaction;

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ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces.

INTRODUCTION
The term 'fugacious' is a synonym of 'ephemeral' defined as, 'tending to disappear' or 'fleeting'. FugaciousFilm builds upon the work on Ephemeral User Interfaces, which 'employ transient materials for tangible interaction with the digital world' [25]. Ephemeral UIs adopt a stance counter to the standard HCI norms of interface stability and reliability by instead employing transience and instability [4]. The majority of Ephemeral UIs developed to date, for example, soap bubble display [21], electric-fan displays [19], candle-flame altars [27] (among others that we review below), have tended to operate as ambient displays in which the digital assumes a background role. In this paper we take a different view, proposing that the transient nature of ephemeral interfaces can also deliver highly attentive interactions in addition to peripheral and calm ones. We have therefore set out to investigate how ephemerality can be deliberately harnessed to encourage a heightened state of close attention involving suspense, tension, anticipation and excitement.

Our approach has been to develop and study a novel soap film interface in which users can touch, push, pull and pop its fragile surface as a way of interacting with digital media that are projected onto the surface. We report the lessons learned from an extended and iterative process of developing this interface that comprised three key phases:

1. Initial technical explorations to establish basic feasibility and techniques.
2. Early prototyping of concept demonstrators in order to further extend and refine these techniques.

3. A user study involving an enhanced Tic-Tac-Toe game that revealed the various ways in which our interface delivered attentive interactions.

By reflecting on this process we are able to draw out two general lessons for HCI. The first is to generalise our findings beyond FugaciousFilm by articulating the broader principles of vulnerability and fragility that explain how ephemeral interfaces can promote attentive interaction. The second is to distil specific guidelines for those who wish to work with interactive soap film interfaces in the future.

RELATED WORK

We begin by reviewing the related work that has inspired and underpinned our approach. We provide an overview of recent research into HCI's engagement with ephemerality before considering its relationship to both ambient and attentive interactions.

Ephemerality in HCI

Ephemeral User Interfaces incorporate transitory materials as a key element of interaction, and have been defined as:

"...a class of user interfaces that contain at least one UI element that is intentionally created to last for a limited time only. The durability of the UI element is determined by its intrinsic material properties in combination with its surrounding ecosystem. While their ephemeral UI element(s) exist(s), ephemeral user interfaces provide a rich and multisensory user experience. ..." [4]

Transient materials such as soap bubbles, fog, wind, and ice have been employed in various tangible interactive systems to enable rich sensory experiences. In Aerial Tune [1] and Interactive Fog Screen [18] the instable nature of airflow or fog has been used as mid-air displays. Interaction in ThanatoFenestra [27] was dependent on movement of candlelight delivered by vulnerable candle flames. Bubble Cosmos [13] and Soap Bubble Interface [25] projected visual feedback onto the smoke-filled bubbles.

A small number of ephemeral interfaces have attempted to combine transitory materials with robust and functional displays and applications, some examples being: MisTable [9], a multi-touch mist display for multiple users; Desert Rain [8], an art installation of water curtain designed for mixing virtual and physical reality; Bit.Fall [17], a network based installation that physically visualized words by falling water droplets; Colloidal Display [15], a soap film display developed to achieve texture deformation for the projected image; and LOLLio [12], a flavour-changing edible interface for playing games.

However, the concept of ephemerality is not restricted to the material aspects of interfaces. Digital ephemerality has also been proposed as a solution to privacy concerns arising from the permanence of data. 'Digital forgetting', the disposal of undesirable digital possessions (e.g. photos, videos) for various reasons, has been recently proposed as a useful approach to tackle this problem [20]. Also, time-limited messaging applications such as Snapchat and Wickr that embody the concept of 'ephemeral data' have become popular [23].

In spite of these promising early developments, many questions remain unanswered as to how ephemerality can be employed in interaction design, and how the material and digital aspects of ephemerality might best be combined to create impactful user experiences.

From Ambient to Attentive Ephemerality

As noted earlier, a considerable proportion of current ephemeral UIs can be thought of as operating in an ambient or peripheral mode. We review previous works used in this ambient manner and then propose the possibility of using ephemeral UIs for non-ambient contexts.

From its inception, the field of ubiquitous computing has been concerned with how to remove the computer from the direct focus of the users' attention, by instead embedding it into the surrounding environment [28]. This has led to a surge of interest in HCI in new forms of interface that are variously described as 'ambient' [7], 'calm' [30], 'invisible' [28] or 'unremarkable computing' [26]. At first glance, the transitory and somewhat immaterial nature of ephemeral interfaces – their smokiness, fogginess or elusive flickering – appears to naturally align with this notion of ambient experience. However, we have been struck by a different inspiration. Trying to interact with ephemeral interfaces, for example trying to peer into them or touch and manipulate them, might in fact command a great deal of attention. In short, ephemerality could become a driver of highly focused and possibly even suspenseful interactions.

The traditional task-driven focus of HCI has led to a considerable focus on the nature of cognitive attention in interaction design [14]. HCI is replete with studies of, and frameworks for, managing attention and distraction with a view to supporting particular tasks, multitasking, and managing distraction and workload [3, 11]. From a different perspective, the field of virtual reality has long been concerned with how the concepts of immersion and presence might explain and inform interfaces that achieve a very particular sense of attention as people engage deeply with virtual worlds [24].

What we have in mind here is engaging users in highly attentive forms of interaction with ephemeral interfaces in which they become intensely engaged with an ongoing experience. Beyond a strong and immediate focus on the experience, this might lead them to experience tension and suspense as explored in previous breath-controlled interfaces [10], or perhaps even anxiety that might generate thrill or lead to enlightenment as discussed in recent work on 'uncomfortable interactions' [2]. With such ideas in mind, we set out to explore the relationship between ephemerality and attentive interfaces through a process of iterative prototyping.

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TECHNICAL EXPLORATIONS OF FUGACIOUSFILM

We begin by summarizing early technical explorations that shaped our approach to ephemeral interaction. Building upon previous soap film projection displays, such as Colloidal Display [15] and Poppable Display [16], we developed FugaciousFilm, a soap film based ephemeral-UI. We chose to work with soap film because:

- It is well known for its fleeting nature;
- Many people will be familiar with the material experience and properties of soap film from childhood;
- It can be used as a projection surface;
- It is easily obtained;
- The duration and other important properties of the material can easily be modified in a variety of ways.

We chose to concentrate on static, or captive, soap film membranes that can be used as touchable screens rather than on free-floating soap bubbles. The implementation of FugaciousFilm therefore comprises two main parts; projection onto a soap film, and detection of interaction with the soap film. We now describe each of these in depth. The combined hardware is shown as a whole in Figure 2.

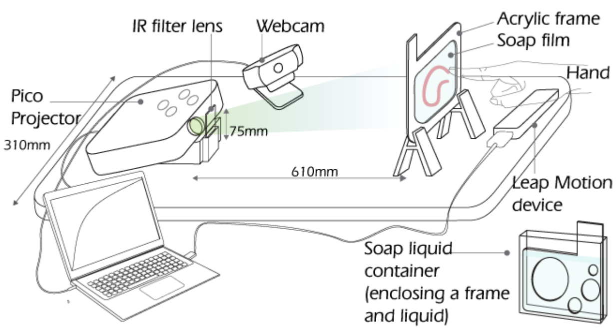

Figure 2. FugaciousFilm system setup.

Projection onto a Soap Film

Due to the transparency, in general, of soap films, projection onto the surface of the film is usually ineffective. Therefore we developed a custom-made liquid soap mixture that enables projection onto the soap film. The image can only be viewed when there are enough surfactant particles to scatter the projected light to the viewer's eyes. After experimentation, we found that mixing white solid soap and glycerin with distilled water produced an adequate film for viewing projections.

When interacting with a projection image on the soap film with a finger, we need to consider possible viewing angles for the user compared to the location of the projector. As the size of the colloidal particles may vary from 1nm to 1μm, both Rayleigh and Mie scattering occur on the surface of the soap film [5]. While light scattered via Rayleigh scattering is visible from any direction, Mie scattering projects light predominantly in the forward direction. In the case of FugaciousFilm, we found that the colloidal particles on the soap film scatter the light from the projection in all directions so that the projection image is visible from both the front and rear side of the film relative to the projector. Initial observations revealed that the vividness between front and back was similar. Therefore, we decided to use back projection in order not to interfere with the projection while interacting with the soap film.

We used an AAXA® P4-X Pico Projector (141×71×31mm, 95 Lumens) in order to keep the entire system to a compact size. As the aperture in the acrylic frame determines the shape of the film, the design and size of the frame may vary depending on the application as shown in Figure 3-a.

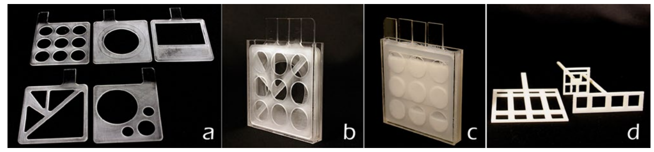

Figure 3. (a) Acrylic frames (80×80mm), (b) frames in one container, (c) container filled with soap liquid, and (d) wipers to create the soap film on the frames.

Interacting with the Soap Film

We explored two broad approaches to interact with soap film displays: creating and destroying (i.e., popping) the film and physically touching and manipulating the surface with a finger. The former requires detection of the presence/absence of the soap film in an acrylic frame, while the latter requires tracking of the user's finger in 3D space.

Soap Film Detection

The soap film in the frame may disappear either spontaneously or due to the user's interactions. To detect the presence or absence of the soap film on the frame, we implemented color tracking via a webcam. When the film is present on the frame, the color of the projection image reflected from the film (which is different from the background color) is visible to the camera. As soon as the film disappears, the background color now becomes visible and this can be used to detect the presence/absence of the soap film. We chose to use a black colored background screen as it makes the task of detecting background color much simpler. The background is detected by using a threshold on the average gray-scale pixel intensities inside the frame region. If the average value of the gray-scale intensities is less than the threshold value, this implies that the background is visible and vice-versa. One limitation of this method is that the detection of the disappearance of the soap film could be delayed if the user's hand is present close to the frame thereby blocking the visibility of the background screen. Detection occurs as soon as the user moves his/her hand away from the screen.

Fingertip Tracking

FugaciousFilm also functions as a 'penetrable' touch screen. For this purpose, we used the Leap Motion® device to accurately track the position of a person's fingertips in 3D space. We place the device in front of the soap film, where the user's fingers approach (see Figure 2). The device uses infrared LEDs and camera sensors to track the motion of the user's fingers up to an accuracy of 1/100th of a millimeter. The x, y, z coordinates of the fingertips returned by the

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device are used to detect the position of fingertip in relation to the soap film frame (x, y coordinates) and to determine the depth of the finger through the soap film (z coordinate). Being able to track fingertips enabled us to explore various ways of interacting with FugaciousFilm including touching (Figure 4-a), pushing (Figure 4-b) and ultimately pulling (Figure 4-c) as we describe below.

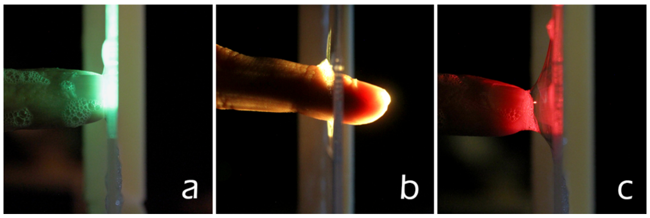

Figure 4. Various z-depth of a finger interacting on the soap film visualized with different colors. A soapy finger is (a) touching, (b) pushing and (c) pulling through the soap film.

Creating a Soap Film of Ideal Duration

Both of the approaches given above have conflicting needs of the soap film. The 'popping' technique requires that a film is pop-able, and the finger detection requires that you can at least touch the film even only briefly. We discuss below how we created a film that satisfies both of these constraints.

In general, the stability and duration of the soap films can be affected by the evaporation of water from the surface. Glycerin reduces this evaporation and so increases the lifetime. The durability of a soap film increases from seconds to many minutes for solutions with just an additional 5% glycerin and up to hours when the solution contains 50% glycerin [6]. Although adding more glycerin into the solution makes the film durable, it also makes it thicker. As a result, rather than popping in the usual way, the film breaks slowly as the surface tears. There is therefore a trade-off between durability and a clean 'popping effect' (i.e. the film disappears in an instant).

We have attempted to strike an aesthetic balance between duration and 'popping' effect. We found that the solution of 2 parts soap, 20 parts distilled water and 1 part glycerin produces a thin membrane that exists temporarily and destroys with a clean desired 'pop' effect. The average duration of a soap film created by our solution on an 80x80mm acrylic frame, when left untouched in room temperature, was 2minutes and 51seconds (n=50, SD 0.67).

EARLY PROTOTYPES

Next, we created three prototype demonstrators of FugaciousFilm in order to test its implementation as an attentive interface, better understand its capabilities, further refine our approaches, and also to inspire concepts for potential applications. We deliberately chose to explore three very different prototypes so as to reveal the potential for various ways of interacting with soap film alongside key features that would deliver a rich user experience. Developing them enabled us to learn about different aspects of interacting with an ephemeral UI including the suspense felt when handling fragile materials, harnessing randomness in a controlled manner, and multi-person interaction.

Prototype 1: Fragile Passcode

The Fragile Passcode prototype demonstrates how the skill of handling fragile material might be harnessed as a means for security in ephemeral interaction. In order to confirm their identity to a system the user must not only remember their passcode but must also remember the motor skills required to manipulate the interface in particular and subtle ways. Initially, the user needs to create a soap film on the frame by using the wiper which then reveals a projected password screen that they can touch in various ways to unlock their passcode. They touch the film with a wet fingertip to draw a pattern (Figure 5-a). Here we can add levels of difficulty into the interaction. In addition to touching the interface, we applied various z-depths beyond the film, requiring the user to find the correct depth while pushing through the film and drawing the correct code. If the passcode is entered incorrectly (Figure 5-b) once or the soap film is broken then the ability to enter the code is removed entirely. Developing this prototype inspired us to think more about the subtleties of touching, especially the depth of touch, and to reflect on the possibilities of 'dangerous' interaction techniques.

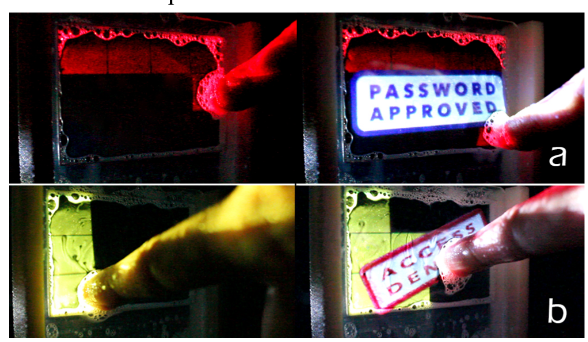

Figure 5. (a) A user unlocks the passcode by drawing a correct pattern on the film with correct depth (indicated by color). (b) Access denied by drawing a wrong pattern.

Prototype 2: Serendipitous Music Composer

The Serendipitous Music Composer prototype explored how serendipity might be harnessed by an ephemeral interface. In short, how might the random nature of an ephemeral material's decay be shaped, controlled, tamed and incorporated into attentive interaction. An acrylic frame with multiple apertures represents a single music track. However, we split the music into its constituent parts and assigned each part to a different soap film circle. When the soap film bursts, the allocated musical part for that circle starts playing (Figure 6-a). The soap film can either be popped by the user's finger or by their breath. Popping all of the films reveals the final music track, with the order of popping building up its layers in a distinct sequence. We added a 'replay' mode in which using the wiper to re-create the popped film (Figure 6-b), refreshes the screen, causing the music to stop and return to the original state (Figure 6-c). We realized that this 'refresh-ability' of soap film might help users cope with its fleeting

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nature and repeat or prolong experiences. It can be assigned and controlled individually.

Figure 6. (a) Music is being played for two popped films (b) the user reforms the soap film with a slider on top-left corner. (c) The music mapped on the recreated film has been stopped (spinning circle disappeared).

Our initial aim for this prototype had been to demonstrate how randomness in interaction with soap film might be harnessed to deliver an aesthetic, in this case musical, experience. However, one of our important findings was that the lifetime of each soap film is not as random as we had first thought. Although the lifetime of the soap film depends on the size of the aperture and environmental conditions, it transpires that identically sized soap films also have different durability depending on their position within the wider frame. Specifically, soap films located in the bottom row usually last longer than the ones in the top row as a result of the soap liquid flowing from the top to the bottom, weakening those at the top while refreshing and therefore strengthening those at the bottom.

Prototype 3: Ephemeral TIC-TAC-TOE

The Tic-Tac-Toe prototype was designed to explore multi-user ephemeral interaction, specifically how time-critical constraints might engender a sense of precariousness when two people interact with a shared ephemeral material. We explored this idea by creating a selection of subtly different variants of the familiar game of Tic-Tac-Toe. Variations involved how the noughts and crosses were represented and how the players changed the state of the game-board.

We introduced a handicap system based around the fragility and natural breakdown of the soap film, a sense of time-criticality that is similar in principle to the use of a chess clock. A player pops the bubble (becomes a nought) while the other touches, preserves, it (becomes a cross) to make their move. However, they must complete these before any of the remaining bubbles pop of their own accord, in which case it is counted as a nought has been placed. In this regard the strength, and hence duration, of the soap film solution directly equates to the difficulty of a game. We also gave a bias to the person playing as nought because if either player breaks the film by mistake, it is counted as a 'nought' (Figure 7). However this bias in nought's favor sometimes worked adversely, as when an unintended film bursts naturally the player with nought loses his/her turn. Our explorations with this prototype revealed how the precariousness of the soap film was also affected by environmental conditions such as humidity, air currents and vibrations that could interrupt or shorten the game. We also learned how the use of a soapy finger could extend the range of interaction and maintain the lifetime of the soap film. Most importantly, we noted how players' anxious anticipation about unintended popping naturally demanded greater attention to their interactions and increased the sense of tension in the overall game experience. This provided the inspiration for our subsequent user study.

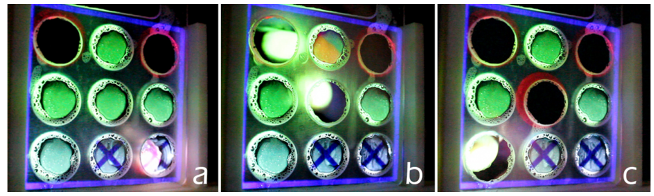

Figure 7. (a) One player is touching the bottom-right film (cross) while (b) the other player pops (nought) the center film. (c) When the user with cross breaks the film by accident, it counts as a nought that helps the opponent win the game.

USER STUDY

The final stage of our exploratory design process was to conduct a user study with a fully realized application of FugaciousFilm. We chose to further develop the Tic-Tac-Toe demonstrator as informal feedback had revealed its potential to stimulate attentiveness and tension. Tic-Tac-Toe also offered the challenge of trying to introduce tension into a relatively unexciting game of limited possibilities while also providing users with a familiar, quick and repeatable task with an inherent motivation.

Pilot Study

We began with a pilot study in order to explore the most appropriate ways in to enhance Tic-Tac-Toe through FugaciousFilm and to assess different possibilities for design of the physical soap film interface and interactions. We invited 10 university students and researchers to participate in a series of trials, each lasting 30 minutes including playing various test games and a short exit interview. Each participant played four different types of Tic-Tac-Toe game which varied in the design of the physical soap film aperture (single aperture, uniform multiple apertures, non-uniform multiple apertures), the kinds of interactions being explored (combinations of touch, pop and push) and the mapping of these to the rules of Tic-Tac-Toe as summarized by Table 1. We anticipated that the sequence of games from (a) through to (d) would involve increasing difficulty and require a progressively more sophisticated understanding of FugaciousFilm. In addition to interviewing participants, we noted their verbal expressions and finger gestures (speed, movement and cautiousness).

Encouragingly, participants clearly grasped the nature of ephemerality as the experience progressed: *"You get the sense of urgency as the time flows during the game"* and noted how this enhanced their enjoyment: *"I tried to put my cross in terms of the rule of Tic-Tac-Toe, then actually putting it without destroying the bubble becomes fun of the game."* In terms of the four different designs, the first variant (a) was the least successful due to its inherent bias towards 'noughts'. The second two were more interesting with the non-uniform apertures (c) being preferred to the uniform

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ones (a): *"The different sized ones were more interesting than the regular ones, because it was more difficult to pop the smaller ones"*.

Frame Design & Interface	Rules
a Uniform Apertures; c Non-Uniform Apertures; Touch / Pop	- Touch = cross / Pop = nought - Two players take alternative turns. - Accidental popping made by the player with cross counted as a nought. - Unexpected popping (by air, breath) also counted as a nought.
b Uniform Apertures; d Single Aperture; Touch / Push	- Each of the nine sections are assigned with either touch or push. - Letters are projected visually on the film. (* Lines are projected on the film in frame-d) - Two players take alternative turns. - First player starts from anywhere with a nought. - Whoever pops the soap film loses the game. - Unexpected popping also makes the player, who's turn it is, lose the game.

Table 1. Table shows the design and the rules of four versions of the Tic-Tac-Toe game demonstrated in the pilot study.

However, it was the single large aperture (d) that generated the greatest excitement: *"Single framed game feels more devastating than the separated uniform holes (a)"*, *"I like this one (the last game) most, it adds so much more tension during the interaction."* Moreover, we also noted that participants were able to improvise some distinctive and interesting interactions with this larger film.

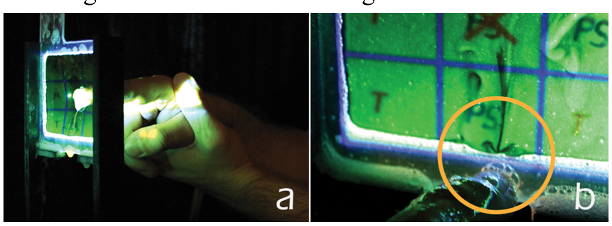

Figure 8. (a) A user holding his hand with the other hand. (b) A user drags the finger to the edge of the frame after his turn, in order to keep the film stable.

One participant held one hand with the other hand to prevent shaking while touching (Figure 8-a) while another learned to always move his finger to the bottom edge of the frame where the film is the strongest when removing it from the film so as to provide the greatest stability (Figure 8-b). Significantly, several participants also noted the good feeling and interactional potential of pulling on the soap film: "*When you put your finger through and bring it out, still doesn't break the film then it feels just great… It feels more visceral, you can see the bubble moving a lot and seems a lot more fragile.*"

Final Design Iteration – Interacting by Pulling

Inspired by our pilot participants' suggestions, we decided to extend the interactional capabilities of FugaciousFilm to include pulling and to incorporate this into the main study. The main technical challenge lay in detecting both the presence of the soap film and whether or not it is still in contact with a fingertip. We took advantage of the optical phenomenon of 'specular highlight'; a bright spot of light that is typically seen on shiny curved surfaces. When the soap film is pulled, its surface near its point of contact with the fingertip becomes slightly curved, and a specular highlight appears (Figure 9). In order to detect this spot, we employed an image processing based method, detecting blobs in images. The image of the frame captured from the camera is first converted into a gray scale image, which is then thresholded (based upon pixel intensity values) to get a binary image. Finally, the blobs are extracted by labeling the connected components [22]. The right blob representing the specular highlight can be detected by searching only for those blobs whose shape and size corresponds to that of the specular highlight.

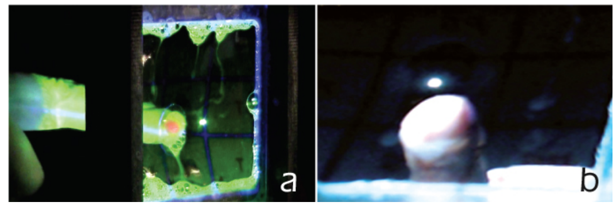

Figure 9. (a) Specular Highlight appears on the film near the finger when it's pulled. (b) Screen shots of the camera view, identifying a blob near the fingertip.

A further subtlety that needs to be considered is variation in the flexibility of the film across its surface. Surface tension of soap membrane directly applies to emotional tension that arises when pulling it. Early testing revealed that the center section could be pulled out the furthest, edge sections a medium distance and corners the least (Figure 10). We therefore tuned our pulling interaction to recognize the whole range of possible distances across the surface of our large aperture.

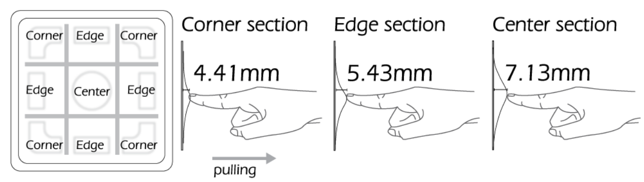

Figure 10. (Left) Regions in the soap film and (Right) an average distance from the baseline the stable soap film can reach for each section.

Main Study

Our main study took the form of a tournament where participants played our Tic-Tac-Toe game on a single soap film aperture – case (d) in Table 1. The basic rules were:

- Players alternated who goes first between games;
- The first player always starts with a 'nought'.
- When it is their turn, a player can choose to put their mark in any position, but must do so using the specified interaction type (push, pull or touch) which is visibly projected onto that section of the soap film screen;
- If player breaks the film, then they lose the game.
- Otherwise, the normal rules of Tic-Tac-Toe apply.

We created three versions of the game, varying them according to which interactions were mapped to which of the nine cells of the Tic-Tac-Toe board (Figure 11-a). We designed the study in the form of a tournament that comprised three rounds: group stages, semi-finals and a final.

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In each round, the two participants involved played all 3 variants of our Tic-Tac-Toe game. After the group stages, the top 2 players in each group progressed to the semi-finals, with two players eventually progressing to the final. In total, 26 games were played since the eventual champion only required 2 games to win the final. We recruited six participants from our university network, 4 students and 2 staff (2 females and 4 males). Participants received a $13 gift voucher for participating while the overall champion and runner-up received additional $25 and $8 gift vouchers. Figure 11-b summarizes the tournament format and the progressions of the different participants who are labeled P11-P16 (P1-P10 were the participants in the pilot).

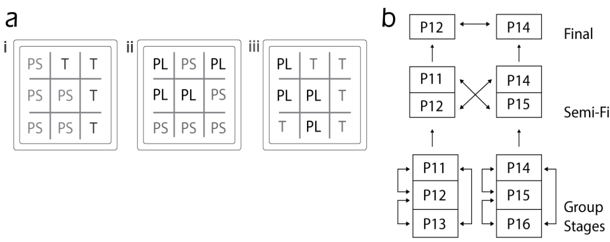

Figure 11. (a) A set of game consists of 3 versions of Tic-Tac-Toe. PS: push, PL: pull, T: touch. (b) Format of the tournament held in the user study.

The tournament lasted in 60 minutes and it was held in the empty lab space. Participants were watching and cheering as spectators while the others were playing their rounds. The whole tournament was video recorded. We have verified from the pilot test that participants express immersed emotion in two ways; through verbal utterances and gestures. Therefore, the moderator instantly marked notable verbal and behavioral feedbacks for later video analysis (Figure 12). Also, there was a final debriefing session with the whole group afterwards.

Findings

We begin with some general observations. The average game duration was 52.6 seconds (n=26, SD 31.8) and most of the games ended by the film bursting during user interaction. Overall, participants appeared to be highly engaged in the experience. They demonstrated and verbalized signs of tension and were able to develop a variety of tactics. The visceral nature of the interface affected many participants' decisions when making a finger movement and some participants developed their own tactics. In addition to putting their marks in the correct position, the fragile material clearly forced participants to be cautious in their motor control. This reflects the result that only 7 games in total were completed in a way that the players succeeded to execute interactions in every section of the film before the soap film had burst, and out of those only 2 games lasted in draw. We now drill down into specific findings. Analyzing our video-recorded observations, we focused on several indicators of attention including specific words expressing tension, finger movements and behaviors such as holding breath.

Intense Awareness of Material and Interaction

During the game, players made repeated verbal and behavioral expressions to suggest that they were very focused on handling the soap film material. Often, not only players but also spectators said, *"This is tense,"* while executing or watching the interactions. After P11 played the first round of tournament he replied, *"It's tense, but this is only round one."* In one instance, P12 sighed deeply as he visibly relaxed after he succeeded to put his cross in the right place. Reactions such as this revealed the intensity arising from having to exert fine motor control over an unstable surface. Moreover, having learned that their fingers need to be wet enough in order not to break the film, participants tended to dip their fingers into the soap solution each and every time before their turn, even when it was already wet. Participants were intensely aware of the fragility of the film when some players did not concentrate on the game tactics of Tic-Tac-Toe but instead focused entirely on executing the interaction successfully. After P15 won the game and before the film had burst, he said to P14, *"You also need to play Tic-Tac-Toe in this thing."*

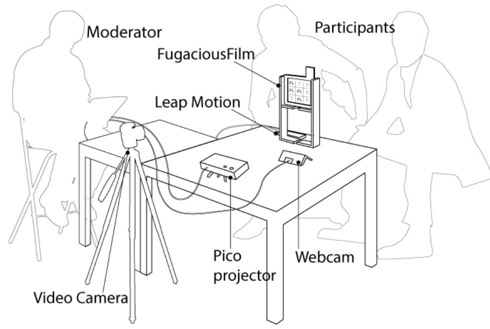

Figure 12. Study setup. Illustration shows how the study has been conducted and recorded.

Ephemerality Rules the Game

We had anticipated that the ephemerality of the interface (i.e., the sense that it might pop at any moment) would create a pressure for players to move on quickly. However, we observed the opposite in many cases. For example, P16 spent too much time at his turn hesitating where would be the 'safest' and 'correct' place to put his mark with the result that film broke before he could make any meaningful move. In a different vein, P15 used this feature of the material as one of the tactics to win the game. In one of the rounds, P15 was intentionally wasting time on his turn while commenting that, "I'm waiting for it to be breakable when it's your (P12) turn." Both cases illustrate how intensity arises from not knowing for how long the surface will remain available or stable for a given interaction, but also how this may be exploited in various ways.

Easy Touch

Participants found touching interface the easiest, initially tried to occupy the sections with 'touch' first, sometimes regardless of whether this was a good logical move in Tic-Tac-Toe. Later on, however, they figured out that touch was usually the 'safest' interaction, causing least movement to

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the film. This realization led to unexpected actions and reactions between the players. In the semi-final, for example, although it was obvious for P11 to defend himself and also occupy a definite chance to win by putting his cross in the center, he instead went for a touch interaction in bottom-right corner (Figure 13-a). Then P14 managed to put a winning 'nought' in the center by pulling the film (Figure 13-b). P11 responded, *"I was more concerning getting you (P14) to pull,"* suggesting that he was trying to avoid the risk of breaking the film by pulling it back.

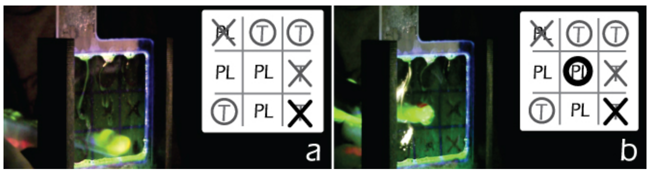

Figure 13. (a) P11 puts a cross on the bottom-left corner although he had to block the center section. (b) P14 pulls the center section successfully and wins the game.

In some instances, participants made delicate decision according to their growing knowledge of how the fragility varied across the surface and also changed over time. In Figure 14-a, P16 was trying to put cross by pushing the top left section in order to avoid the nought winning the game. But after several trials, the film became already thinner as some of liquid had evaporated while some had flowed to bottom. Then P16 changed his mind to safely put a cross on the top right corner (Figure 14-b) by 'touching'. In spite of this tactic, P15 managed to push the upper left corner and won the game (Figure 14-c).

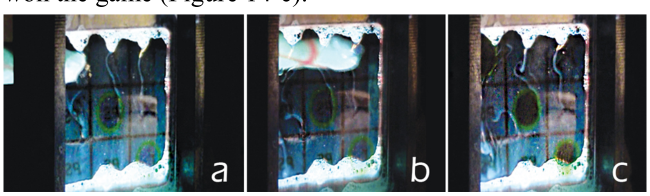

Figure 14. (a) P16 attempts to push. (b) But decides to make a safer move by touching the top-right corner. (c) Then, P15 pushes through the top-left section and wins the game.

Dangerous Push and Pull

The variant of the game involving both push and pull interactions was found to be the most demanding. Interestingly, they held opposing opinions about the difficulty of each case. P14 recalled that the vulnerability of the soap film was reinforced when it fluctuated after he pushed, *"When I push, I need to push quite further but then I also need to pull back out and it feels dangerous to burst the bubble."* Reflecting this, although participants grasped the fact that they could push a wet finger relatively far through the film, they remained especially focused, cautious and tense when performing this particular interaction compared to other interactions. One participant yelled, *"I can't put my finger anymore through"*, although he knew that he can push further and ultimately did so. This tension that participants felt on such occasions could also be seen from variations in the speed of their finger movements as players cautiously slowed down when they pulled back after pushing the film. However, some participants reported the opposite feeling. Later in the debriefing session, P11 recalled that 'pushing' was easier than 'pulling', *"If you need to pull you need to push any way."* This feedback reflected the observation that although they had to push the film to a sufficient depth to properly engage it with their finger, some participants were tend to touch slightly and then pull back.

Summary of User Study

While individual tactics and experiences varied somewhat, it was clear from the study that, in general, players:

- Were able to perform pushing, pulling and touching.
- Quickly learned the delicacy of touch required to do so.
- Also learned how the interactional properties of the soap film varied over its surface area and over time.
- Were able to tactically exploit all of this knowledge.
- Paid very close attention to the interface.
- Found this absorbing, tense and often suspenseful.

DISCUSSION

Our extended design process, from initial technical explorations, through early demonstrators, to the user study, reveals that it is possible to create an ephemeral interface from soap film that encourages highly attentive, often suspenseful interactions. From a technical perspective, we have shown that it is feasible to realize multiple forms of interaction with a soap film surface – touch, push, pop and also pull – with sufficient reliability to deliver a robust and playable game. Experientially, players found this game to be enjoyable, with the interface generating tension and excitement while also introducing new tactical possibilities. Our discussion now draws out two wider contributions from this work: (i) reflecting on how ephemeral media engenders attentive interaction through vulnerability and delicacy; (ii) distilling key techniques for interactive soap film interfaces and proposing other applications beyond games that can benefit from the ephemeral quality of the soap film.

Exploiting Vulnerability and Delicacy of Interface

Whereas previous work has explored how ephemeral media, including soap film, can be incorporated into ambient interfaces, we have shown how they might also enable highly attentive ones. We argue that these attentive, sometimes even tense, interactions arise from a combination of the inherent vulnerability of the material and the resulting delicacy of various interactions with it. This emphasis on the material qualities reflects previous discussions of uncomfortable interactions within HCI that have argued how the 'visceral' (i.e., material) qualities of interaction can enhance suspense [2].

A soap film interface is highly vulnerable. We have seen how the liquid nature of the interface makes this vulnerability dynamic. As the soap suspension flows under gravity and the moisture dries out over time, it forms stable 'black film', where the thickness became less than the wavelength of light so that it appears black [6]. The tension of the surface

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gradually increases until this status and therefore, it directly equates with the vulnerability of interface. Our study revealed how users also tried to anticipate the vulnerability of the interface to a degree, which further reinforces feelings of suspense. In turn, vulnerability demands a certain delicacy of interaction. Users have to manipulate the interface carefully, concentrating closely to exert fine-grained motor control over their movements. Delicate finger movements on the soap film induce tension to a positive effect requiring the user to pay especially close attention. FugaciousFilm affords a rich repertoire of interactions to play with, each introducing its own subtle forms of delicacy; touching, pushing, pulling and popping each have their own distinct 'feels'. We claim that it is the partial predictability of both vulnerability and delicacy (having a general but somewhat imprecise sense of how it varies) that is especially powerful for generating suspense in direct interactions on such fragile materials. Especially, compared to the more random behavior of free-floating bubbles introduced in previous works, enhanced use of static soap film with controlled durability opens another potential area of EUIs that has not been covered by ambient and calm interactions, though this proposal needs exploring in further research.

We expect designers may enjoy considerable flexibility with regard to how they influence durability, most notably by varying the strength of the soap solution and size and shape of the aperture, as well as by tuning software in order to apply to a wider range of interfaces. The user can also employ material techniques to enhance these interactions such as using a wet finger. Finally, the ability to refresh the soap film with the 'wiper' tool also gives these users a degree of direct control. Thus, FugaciousFilm is more than just a vulnerable material; it is an interface in which vulnerability is partially predictable and open to various forms of control by both designers and users. We propose that researchers who wish to develop other ephemeral interfaces based on different materials (we see soap film as something of a 'probe' technology in this regard) will need to ensure that they provide a similarly broad repertoire of characteristics and techniques specified in our findings.

Extending Interactions with Soap Film Displays

Our second contribution lies in extending the repertoire of techniques for designing and interacting with soap film interfaces, adding to HCI's growing body of 'craft knowledge' concerning this particular interactive material.

Balancing the Duration of the Soap Film and Experience

As discussed above, we found that designers can systematically vary the durability of the film and hence vulnerability of the display and hence the likely duration of the experience. The soap liquid solution we have created contained; 10g of a white solid soap, 100g of distilled water and 5g of glycerin, which created stable soap films that lasted for a mean average duration of just under three minutes. This average three minute duration sets a likely upper limit on the overall user experience. The longest game across the whole tournament lasted 2 minutes and 10 seconds. Further research is required to systematically explore how alternative mixtures, apertures and even environmental conditions such as temperature, humidity and air currents might affect this.

Introducing 'Pulling' Interactions to Soap Film Displays

We have extended the repertoire of interaction techniques for soap film interfaces beyond pushing, touching, and popping as demonstrated by previous projects [16, 25] to also include 'pulling'. This mode of interaction has some distinctive interactional properties. We observed that some participants tried to hold or grab the film by bending their finger like a hook (Figure 1-d) suggesting the potential to support various kinds of pulling gesture. Although it was obviously seen that the film is not quite graspable, tangibility of the material was inducing the interaction. As pulling distance physically corresponds with the degree of the surface curvature, we envision that this mode of interaction to be extended further to multi-finger gesture, such as 'pinching'.

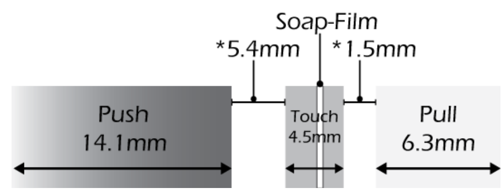

Figure 15. The ranges for push, touch, pull and *inactive regions.

Ranges for Touching, Pushing, Pulling and Inactive Regions

Our experience suggests that each of touching, pushing and pulling interface to have its own distinctive physical range of movement as summarised by Figure 15. In order to avoid a jittery interaction and also gently force the user to perform clear gestures with an appropriate delicay of touch, we found it necessary to introduce 'inactive regions' – buffer zones in which no interaction was deemed to be happening. Between touch and pull, we set the value to 1.5mm, and between touch and push we set even longer inactive region (5.4mm) in order to distinguish 'push' more clearly from 'touch' as they are continuous actions. Due to this clear gesturing, when participants perform each action, the film reacts in a typical way for that particular action (such as making large fluctuations after a pull or push). Thus, the participants deliberatuely adjusted their actions so that the result of their action wouldn't break the film.

Applications beyond Games

The games sector is a major domain for interactive technologies in its own right. Beyond our test bed Tic-Tac-Toe game, we also suggest that our approach can be applied to a wider range of games that can benefit from a variety of skillful touch interactions. There are other potential areas of application such as serendipitous music interfaces, demonstrated in one of the early prototypes. We also envisage potential applications in museums and galleries where visitors may benefit from an intense focus on delicate things. Science museums are likely to exhibit this kind of new media where hands-on experiences on various materials

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are appreciated. More speculatively, we suggest new approaches to engaging with increasingly ephemeral social media such as tweets and Snapchat photos by enhancing the experience of fleeting moments of interaction. The physical cue generated by the disappearing material would enhance the tension while viewing the image, before it is lost.

CONCLUSION

To conclude, our explorations with FugaciousFilm reveal that ephemeral interfaces can deliver highly attentive and even suspenseful experiences as well as ambient and calm ones, demonstrated in related works. While we have focused on soap film interfaces so far (extending their repertoire of interaction techniques as a result), we anticipate that it is possible to replicate this general approach with other ephemeral mediums and interface technologies, especially if their properties allow for the flexible control and partial predictability of both vulnerability and delicacy. From our experience designing the FugaciousFilm prototypes, we believe that ephemeral materials with such properties can be employed to build solid interactive systems that encourage focused transient interaction. Therefore, we propose FugaciousFilm as the first step towards exploring this new design space of ‘attentive interaction with ephemeral material’.

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