RESEARCH-ARTICLE

Paper mechanisms for sonic interaction

STEFANO DELLE MONACHE, IUAV University of Venice, Venice, VE, Italy

DAVIDE ROCCHESSO, IUAV University of Venice, Venice, VE, Italy

JIE QI, MIT Media Lab, Cambridge, MA, United States

LEAH BUECHLEY, MIT Media Lab, Cambridge, MA, United States

AMALIA DE GÖTZEN, University of Padua, Padua, PD, Italy

DARIO CESTARO

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Paper Mechanisms for Sonic Interaction

Stefano Delle Monache, Davide Rocchesso
IUAV University of Venice
stefano.dellemonache@gmail.com, roc@iuav.it

Jie Qi, Leah Buechley
MIT Media Lab
jieqi@mit.edu, buechley@mit.edu

Amalia De Götzen
University of Padova
degotzen@dei.unipd.it

Dario Cestaro
dario@dariocestaro.it

ABSTRACT
Introducing continuous sonic interaction in augmented pop-up books enhances the expressive and performative qualities of movables, making the whole narrative experience more engaging and personal. The SaMPL Spring School on Sounding Popables explored the specific topic of paper-driven sonic narratives. Working groups produced several sketches of sonic interactions with movables. The most significant sketches of sounding popables are presented and analyzed.

Author Keywords
Pop-up books, sonic interaction design

ACM Classification Keywords
H.5.5 Information Interfaces and Presentation: Sound and Music Computing

General Terms
Design

INTRODUCTION
In his classic lecture on the foundations of interaction design [32], Bill Verplank describes the essence of computational objects as "representation for manipulation", and he summarizes the history of human-computer interaction styles as a process starting from symbolic, going to iconic, and eventually converging to enactive representation/manipulation. Among non-computational objects, pop-up books are perfect examples of the entanglement between representation and manipulation, both serving a non-linear narrative. Therefore, it is not surprising if paper engineering has attracted the attention of several computer scientists both as an application field for computer-assisted design [20, 21, 25, 31] and as objects to be augmented with computer technology [27].

Using Verplank's terms [33], we can say that a pop-up book embeds both display and control, and it affords expressive interaction through continuous controls. In other words, interaction in pop-up books is mainly based on handles rather than buttons, although hidden figures may suddenly emerge in a seemingly discrete manner. Conversely, most attempts to embed electronics into books have privileged discrete interactions, using switches and programmed displays (typically, light or sound sequence playback). By exploiting continuous interaction, the augmentation of pop-up books may encourage the production of expressive gestures, in such a way that the book itself may become a performative object. In this respect, focusing on auditory display and procedural audio [16] can produce interesting results, as a complement to the motion of visual representations on paper.

Sensors that continuously detect force, light, displacement, or bending can be embedded in paper mechanisms and provide control signals for sound synthesis [12]. It is even possible to use conductive pigments and threads in the paper-making process to develop seamless composites that feel like regular paper [9, 24, 27, 4].

As seen from a spectator [28], a popup book appears highly expressive: fantastical when effects are not obviously related to gestures and suspenseful when the effects happen suddenly. Movable books depend on negotiating "a balance between the narrative's linear storytelling and the visual's interactive and spectacular" display [15]. Sonic interaction design has the potential to introduce yet another performative dimension and a new level of engagement. The purpose of this paper is to give an overview of the elements that interaction designers can employ to build paper-driven sonic narratives. We reflect on how sound and music computing on paper may exploit tangible, movable interfaces as significant tools for human-computer interaction design.

Our reasoning develops as follow: we review classes of basic pop-up mechanisms and assess their aesthetic potential; we present basic techniques for augmenting pop-ups with electronic sensing; then, we analyze the actual role of sound on paper, and the narrative potential of sound with respect to various pop-up mechanisms; we introduce possible approaches to sound generation and diffusion, and reflect on their impact in terms of effectiveness and aesthetics of interaction. Finally, we report several initial sketches of paper-driven sonic narratives, produced in a workshop setting. The sketches and the emerging sonic narratives are analyzed and assessed.

BASIC POP-UP MECHANISMS
Pop-up mechanisms can be classified into two main kinematic categories: *Spherical* mechanisms pop out of the page

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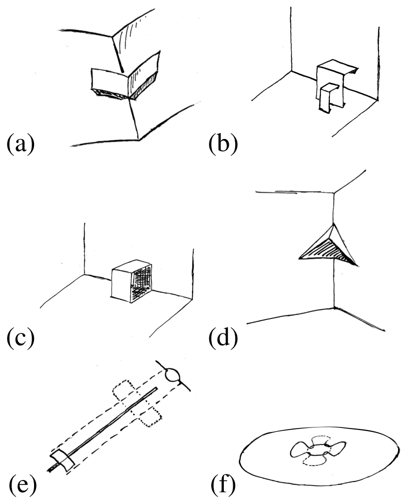

Figure 1. Basic spherical (pop-up) mechanisms: (a) v-fold, (b) double-layered glued parallelogram, (c) double slit parallelogram, and (d) angle fold with single-slit. Basic planar mechanisms: (e) sliding pull tab and (f) wheel.

and *planar* elements lay flat along the plane of the backing spread [34]. Most spherical elements are kinematically coupled to the angle at which the page is opened, that is, they pop-out due to opening and closing of the backing page or flap. These mechanisms can be further broken down into *parallel folds* which provide pop-up motion parallel to the page opening (Figure 1.b and Figure 1.c) and *angle folds* which pop-out at angles to the page opening (Figure 1.a and Figure 1.d) [6]. Planar mechanisms are manipulated independent of page opening and closing. These are categorized as pull tabs (Figure 1.e) that slide along the backing plane and wheel mechanisms (Figure 1.f) which pivot along the backing plane [6].

Pop-up elements usually achieve maximal extension at either 180° (Figure 1.a) or 90° (Figure 1.b) of opening. Many of these emphasize the sudden emergence of the third dimension, as exploited by steps and figures that stand-up. Here the goal is usually a static three-dimensional scene. Repeated and continuous opening and closing of the page can also lead to interesting interactions. One example is a simple slit-and-fold technique which can be used to produce an effective mouth mechanism, in which the mouth opens and closes as the page opens and closes, respectively. Pull-tabs and wheels are planar, but they are often linked to parallel fold mechanisms to create elements that pop out of the page [34]. Wheel and pull-tab (or slider) mechanisms can be easily combined to produce secondary mechanisms such as the crank-and-slider which converts between linear and circular motion (as displayed in Figure 7).

When a person interacts with a pop-up, the spherical action (the opening of the page) happens first. Planar elements (pull tabs and wheels) are interacted with, once the page is open and the mechanisms are accessible to the viewer. The latter elements do not depend on opening and closing the page, thus expanding the range of gestures the user can make to interact with the pop-up interface.

ELECTRONIC AUGMENTATION OF POP-UPS

For basic spherical mechanisms, since all pop-up motion is kinematically coupled to the motion of opening and closing the page, all behavior of these elements can be determined using only the page opening angle. For electronic augmentation of these mechanisms it is critical to sense the fold angle of the main page.

Existing electronically augmented books generally sense only whether or not the page is fully open. The main technique, as used in commercial greeting cards, is a mechanical tab switch attached to the spine of the page. This technique is wonderfully implemented in the pop-up book "Birdscapes" in which each pop-up spread erupts in the sound of bird songs when the page is fully open [7]. Recent commercial electronic books also employ light sensors embedded in the page which are exposed to light only when the page is fully open, as in the case of Hallmark's recordable books[1] series, which obviates the need for moving mechanical components. For a more effective augmentation, it is preferable to sense not only the extremal states of the page (fully open, closed), but also the degree of the opening in order to correlate the feedback with the gesture of manipulating the page.

It is straightforward to sense fold angle using a rotary potentiometer or encoder. However, this requires placing a rigid and bulky mechanism along the axis of folding, the center of the spread, which may reduce the aesthetic functionality of the page. An alternative method of mechanical coupling is to embed a resistive stretch sensor [2], an elastic string with length-dependent resistance, across the fold so that the sensor stretches when the page opens. Light and flexible sensors can be integrated into the spread more discreetly than potentiometers and encoders. The measurement is indirect and the elastic sensor exerts a spring force that pulls the fold closed, altering the nature of the interaction.

Another method of fold angle sensing employs magnets and Hall-effect sensors. A small magnet is inserted into one page and its movement is tracked with a Hall-effect sensor on a separate page. Both magnets and sensors are small and flat enough to be embedded into the backing spread without significantly altering the look and feel of the page (see the *Telescrapbooks* project for an example implementation [17]). Finally, thin and flat electrodes made from conductive foils, textiles or threads can be completely integrated into the paper and used for capacitive sensing. While capacitive sensing is prone to interference from surrounding electromagnetic fields and requires proper grounding, it is the most aesthetically versatile method because the sensing element, the electrode, can be made from any conductive material in any desired shape.

The movement of planar mechanisms (pull-tabs and wheels)

[1] `http://www.hallmark.com/online/in-stores/recordable-storybooks/`.

[2] `http://www.imagesco.com/sensors/stretch-sensor.html`.

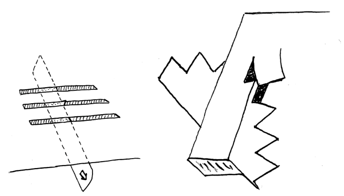

Figure 2. Mechanisms for obtaining sound from moving paper.

can be sensed in many different ways. Sliding and rotary mechanisms can be obviously related to faders and rotary potentiometers like the ones found in audio equipment. For quick sketches, made to survive a few manipulations, variable resistors can be directly built on paper by using a layer of graphite and a movable electric contact [24, 4]. Flat and flexible potentiometers are also commercially available for building more durable interfaces[3]. Stretch sensors also can be easily coupled to sliding tabs or rotating wheels. In addition to sensing changes in longitudinal position or rotation, they provide a return mechanism that pulls the tab or the wheel back to a rest position.

Gestural interactions with the page can also occur without moving mechanisms. For example, people bend and apply pressure to pages. Force sensors are especially easy to embed in paper and can be easily made by layering a force-sensitive resistive material, such as Velostat, between conductive electrodes [24, 27, 26]. These sensors are particularly versatile since the shape of a sensor can be customized.

SOUNDS ON PAPER

Paper mechanisms can produce sounds without any electronics. There are specific paper-engineering tricks to produce a snap sound when a paper door is opened or closed, the gratifying result of a continuous effort. In other cases, the continuous manipulation of book elements is rendered through mechanical sound, through repeated plucks (as in Figure 2) or continuous sliding. These are the cases of paper saw-teeth made to produce repeated plucks, or of direct tactile exploration of the texture of different materials. Some examples of paper-generated noises can be found in the book "White Noise" by David Carter [5], a collection of spreads with abstract moving compositions designed to delight eye and ear.

The addition of electronics into pop-up books, besides widening the palette of possible sound effects, allows authors to create narratives that would be difficult to create with purely visual or paper-mechanical means. For example, in a sonically-augmented pop-up sketch, the explosion that follows the action of pumping a balloon can be rendered by synthetic sound [12].

The narrative dimension

In pop-up books, temporality is the greatest common factor that paces the reader's entanglement, continuously challenging him or her with successions of constraints and degrees of freedom in the acts of looking, scanning, and contemplating [15]. Scenes and characters are revealed according to precise choreographies of spatio-temporal hierarchies. Often a single tab is used as one-to-many control mechanism, in order to generate several delayed actions spread along the scene. Delay lines are exploited to introduce surprise by emphasizing the autonomous behavior of characters and scenes. Temporal strategies, that facilitate syncing between display and text, allow to achieve strong narrative effects. For instance, the motion cycle mechanism introduces the illusion of perpetual movement, playing with the rhythm and pace of repetitive motion [15]. Time is suspended, and the tight coupling between display and storytelling reinforces the whole narration. The reader acts on the narrative dimension as a wizard-of-Oz, by embodying both the roles of performer and spectator observing himself or herself performing actions on and through the book [11].

Time is naturally linked to sound, and sound producing events are always connected to movement [19]. Everyday sounds and audio effects, such as echo and resonance, or tempo-related rhetorical devices (*accelerando*, *rallentando*, etc), are known to embody meaning and micro-narratives based on common sense [1, 2]. For example resonant walking sounds with sudden accelerando may give the impression of somebody running away from something. Interactive sound may enhance the whole narrative dimension by sustaining or contradicting the visual and tactile presentational modes [30]. The narrative dimension of sound emerges in that balance between the use of tabs, levers, buttons and the choreographic and dynamic processes triggered or controlled during the manipulation, which in turn affect the negotiation between storytelling and display. Reeves et al. developed a framework of possible strategies for designing spectator's experience, wherein manipulations and effects may shift from secretive to revealed [28]: (i) Secretive sounding mechanisms hide both manipulation and effect, as it might be the case of static background soundscapes; (ii) in expressive sounding mechanisms, both manipulations and effects are revealed or amplified, with a tight coupling between action and sound; (iii) magical sounding mechanisms hide or reduce manipulation while revealing or amplifying sonic effects; (iv) in suspenseful mechanisms, effects are almost hidden while the manipulation is revealed or amplified. The latter strategy, apparently contradictory, may exploit "thresholds of silence" to provoke curiosity and increase expectation by anticipation, as in waiting for a confirmatory snap.

The sonic identity of augmented movables and computational objects is potentially *schizophonic*, i.e. their computational capabilities make the relationship between a physical object and its sound arbitrary [22]. In this respect, the sound design of a "movable representation for manipulation" may consider the typology of interactive commodities proposed by Hug [23], where the most relevant phenomenological properties of the audible (pervasiveness, temporality, spatiality, sociality, emotionality, physicality) are taken into account as means to inform sound design strategies. Reframing Hug's taxonomy, (i) electroacoustic sounds of *authentic* movables are simply aimed at rendering the sonic quality of the actual sound producing process (e.g. a door hinge,

[3] `http://www.spectrasymbol.com/softpot.`

a scroll mechanism, a lever); (ii) still strongly identitarian, movables can be *extended* with additional capabilities, and the sound design operates on the symbolic meaning of the action-sound discourse (e.g. a pulling tab of a door may anticipate to the reader an imminent danger for the main character of the story) ; (iii) potentially all abstract movables are *placeholders*, that is they can be completely redefined through sound (e.g. a rolling wheel may turn into a dial, a steering wheel, a fan, etc.) ; (iv) *omnivalent* movables are multifunctional and emphasize the communicative aspects (e.g. a sliding tab may give in turn the mood of the page, become a "weather tuner", a magic browser and so forth). The sound design of *omnivalent* movables is highly evocative and completely detached from the form and the "virtual" physical properties of the movable. Finally, the main challenge is to establish meaningful connections between narrative discourse, aesthetic attributes of paper mechanisms and dynamic properties of some digitally-driven sound models [13].

Where to put sound synthesis

Sound synthesis needs computer power, typically much more than is available in microcontrollers. With a microcontroller the production of a square wave at a controllable pitch is straightforward, just by using an internal timer to pulse an output pin. Reproducing an arbitrary waveform is less obvious, but still manageable using two timers, one triggering at sample rate, and the other modulating the duty cycle of a PWM (Pulse-Width Modulated) signal according to each sample value. Although the sound produced with PWM is generally harsh, it may be acceptable for some applications, especially if filtered at the audio output stage[4]. Moreover, it is only with procedural audio that sound can truly become interactive, when sound-model parameters are coupled to control signals. In sum, only elementary sound models can be actually implemented in a microcontroller.

In order to approach sound as a central design dimension for an interactive book, it makes sense to think of the book as a controller in the classic computer music view [10]. The number crunching required by audio-signal processing and synthesis is better left to specialized environments that run on general-purpose or embedded computers. Examples of such systems are `Max/MSP`, `PureData`, or `SuperCollider`, where a central computational engine can receive and dispatch control signals from and to clients of various kind.

Sonic interaction designers look for ways to rapidly produce sonic interactive sketches, without diving into low-level signal processing. Sound models should be made accessible through descriptions and handles that are compatible with everyday experiences. For example, a designer may want a sound of friction when a screw is turned, in such a way that the sound gets harsher as the connection gets tighter [30]. This is possible, under `Max/MSP`, with the `Sound Design Toolkit` [14], a library of physics-based sound synthesis algorithms, available as externals and patches[5]. While working on sound design with such sophisticated tools may seem to contradict the aesthetics and spirit of pop-up books, it is indeed the proliferation of powerful general-purpose computers, often in the form of mobile devices, that may give new sense to pop-up books and cards, as soon as a they can be connected with such computing devices. They may become manipulative appendices of computers or, in computer music terms, controllers. But it is not just the performative action through special mechanisms that is of interest here. A sound-augmented pop-up book affords a form of explorative, non-linear narration that makes it something different from a musical instrument or a sound controller. In this respect the book-computer combination can be read more as a computational augmentation of the book than a special interface for the computer.

Where to put the speakers

If the location of the computational engine for sound modeling does not affect the experience of a sonic pop-up book, conversely the actual positioning of loudspeakers is quite crucial. If we want the book to become the focus of attention and the locus of an embodied experience, loudspeaker systems should not be far from it. Although the ventriloquist effect may help compensating the physical displacement of the speakers from the manipulated object, putting the speakers in the object itself greatly enhances the unity and coherence of experience [30]. As soon as all the feedback channels (visual, tactile, proprioceptive, and auditory) are consistently bound together, the book ceases to be perceived as a controller and becomes an all-around interactive object.

Paper speakers are possible [31, 9], although they require high power to deliver weak and distorted signals. A viable alternative is given by piezo speakers, which are inexpensive, easily embedded between layers of paper, and work with voltage and current limited to a few Volts and milliAmperes, respectively. Their frequency response is far from flat, and they can be severly nonlinear. Even though adding some feedback electronic circuitry can mitigate such defects [3], it is often practical to just adapt the sound design to the actual speakers. By embedding piezo speakers between paper layers, the paper sheets themselves can act as vibrating membranes that increase the radiation efficiency.

Embedding a few piezo speakers in a spread allows a variety of effects based on spatio-temporal unfolding of sonic sequences. Brief sound bursts emitted at different points can convey the sensation of objects that traverse the page and, for carefully-chosen inter-stimulus intervals, a perceptual phenomenon known as auditory saltation can be induced [29]. Continuous spatio-temporal gestures can be veridically conveyed with just a few emission points. Piezo speakers can be input devices as well. It would be possible to detect contact on different areas of a spread, thus engaging the user in a complex intercourse with the page, mediated by sound-based co-located input/output [8].

[4] For example, sine wave generation (`http://interface.khm.de/index.php/lab/experiments/arduino-dds-sinewave-generator/`).

[5] `http://www.soundobject.org/SDT/`.

THE SAMPL SPRING SCHOOL ON SOUNDING POPABLES

The SaMPL Spring School on Sounding Popables[6] took place in May 2011 at the Conservatory of Music "C. Pollini" of Padova, Italy, and was organized by SaMPL[7] lab in collaboration with the Interaction Design Research Unit[8] of IUAV - University of Venice. The school was aimed at exploring the topic of paper-driven sonic narratives, wherein interactive movables are instrumental to control sound synthesis engines and provide expressive sonic interactions. Twenty-one students (MA and PhD from design, engineering, and musical studies), grouped in five teams, were involved in three days of hands-on design activities aimed at experimenting with paper engineering, sensors and actuators, and with sonic augmentation. Participants were initially exposed to basic paper engineering techniques, fundamentals of paper computing, and introduced to the `Sound Design Toolkit` [14]. On the first day each team received a basic assignment, aimed at facilitating quick sketches of sounding pop-ups, and building the necessary chain of control, from paper mechanisms, to sensing and sound synthesis. The basic assignment required the coupling of a basic interaction, such as pulling the tab, turning the flap, spinning the wheel, pushing, sliding the character, with a specific sound model, such as friction, crumpling, rolling, bubblestream, and impact. The emerging basic narratives and affordances were instrumental to set a basis for ideas generation and prototyping. In the remaining two days teams were free to develop their projects under the supervision of tutors. Resulting sketches were presented and collectively evaluated. In this section we describe the teams' works and reflect about different design strategies resulted in coherent and engaging narrations.

Team 1: Good Morning! [Sara Adithya, Carmen Canale, Dario Khademi, Luca Murgia, and Michele Viel]: the basic assignment of this team was to combine a pull-tab with a friction sound. In figure 3, the scene of this popable describes the interior of a room, where a woman is about to raise the shutters. The narration is meant to convey the pleasantness of waking up immersed in nature. By pulling the tab the reader can open the shutter and look at a natural landscape out the window. A linear contact potentiometer is placed under the tab and its ends fixed to the spread. Two small, flat magnets, one visible on the tab and one placed just behind the potentiometer, are used to keep the pressure constant on the sensor and read the position along the strip. The sound design develops on three layers. The tab's displacement is sonically augmented with a squeaky, wooden-like sound feedback, which is associated to opening the shutter. The squeaky sound stresses the authentic value of the shutter, adding body and weight to the virtual mechanism behind. When the shutter is almost fully open, a harp musical scale is played as soon as the landscape is revealed through the window. The harp sound is strongly symbolic, extending the shutter with magical properties, a sort of gate, an access point in the hand of the reader-manipulator. Finally a background soundscape of trees, river and singing birds fades in, to accompany the scene. The soundscape is confirmatory and highly evocative, with the specific function of giving voice to the landscape and coloring it of a diffused pleasantness.

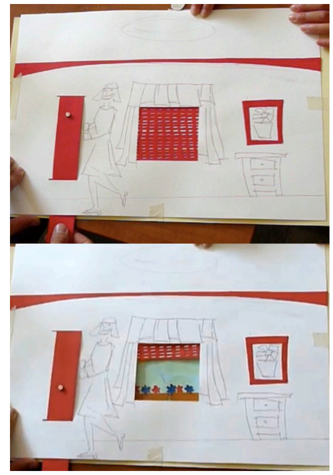

Figure 3. Good morning! As the shutter opens a natural landscape is revealed and a harp scale conveys a sense of magic and pleasantness.

Team 2: Flying Away [Francesco Bergamo, Luca Danieli, Alberto Elizondo, and Annalisa Metus]: The sketch in figure 4 illustrates an immersive environment wherein a cat tries to catch a bird, causing the birds to fly away from the tree toward a bank of blue clouds. A crumpling sound evokes the crackling of the branches of the tree being left by the birds. The basic assignment behind this narration was to combine the action of "turning the flap" with the crumpling sound model. In this sketch a V-fold mechanism moves the cat toward the tree when the card is being opened, and a sliding tab is glued to a lever to control the movement of the birds. The sudden showing of the cat conveys the imminent danger for the birds, the reader is spurred to intervene in the narration and undertake a proactive behavior. The non-linearity of the tab mechanism, strengthened by the resistance of the stretch sensor used to sense its displacement, affects the effort required to operate the mechanism and free the birds. The reader's expectation is increased by asynchronous rendering of tactile and visual feedback, and further amplified by the evocative, resonant crackling sound occurring when the tab is almost fully pulled, with the maximum tension of the stretch sensor and the birds in flight. The sound feedback acts as a reward to the reader for the well-accomplished action, even connoting the movable with a moral quality. The action-sound discourse represents a good example of suspenseful strategy, the manipulation is amplified whilst the effect is displayed as confirmation and resolution of the cliffhanger in such a way created.

Team 3: Spinning Around [Maria G. Astolfo, Marcella Mandanici, Alberto Moro, Davide Panizza, and Stefano Trento]: In the sketch in figure 5, the reader pulls the tab to move the pulley and rest the basket of flowers on the balcony. While the basket is lowered, a human character rotates with the pulley and picks a heart from the left upper corner of the page, as soon as the gift is on the balcony. The basic assign-

[6]`http://soundingpopables.wordpress.com/`.
[7]`http://www.sampl-lab.org/`.
[8]`http://www.iuav.it/interazione/`.

Figure 4. Flying away. As the pages open a cat pops out to catch the bird. Pulling the tab on the left makes the birds fly toward the clouds.

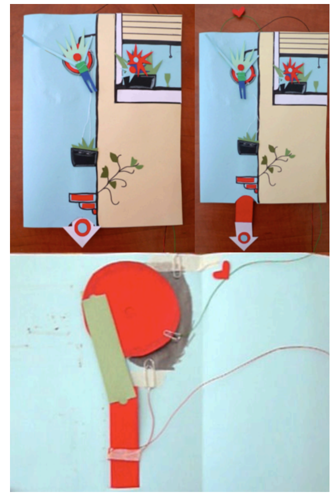

Figure 5. Spinning around. A pulley causes a heart to pop up. A potentiometer is implemented by coupling the paper clips on the crank-and-slider mechanism with graphite.

ment of this team was to couple the action of "spinning the wheel" with the rolling sound model. In the final sketch the rotary mechanism is combined with a slider in order to obtain a crank-and-slider mechanism to rotate the pulley with the pull-tab. A potentiometer made with graphite and movable paper clips senses the rotary movement to control the sound feedback. The up and down movement of the basket is inherently expressive, with a tight coupling between manipulation and effect. The rolling sound associated to the pulley is highly descriptive, stressing its authenticity by adding a sense of effort and weight to the movement. On the other hand, the heart showing up results in a magical movement and surprising effect. Not only the heart reveals outside of the physical space of the page-interface, but also its showing up is anticipated by two short sparkling impact sounds occurring when the basket touches the balcony. Although a little ambiguous, this sound is functional to display auditorily the connection (between the basket and the balcony), while emphasizing on the symbolic level the omnivalent identity of the character (the heart). Interpretation is left open to the reader, whether the meaning attached to the gift is returned (by who?) or gives rise to hope (of confirmation). As sound design hypothesis, it would be interesting to observe if different durations of the impact sound may induce a sort of *legato* effect between the two events of contact of the basket with the balcony and the emergence of the heart, thus cognitively affecting the causal link and addressing cues for interpretation. Specific durations may be exploited for instance as modulators of ambiguity.

Team 4: Squish [Giuseppe Burdo, Giulio Moro, and Roberto Picerno]: This simple scene (see figure 6) makes the sonic interaction highly playful. The basic action of pushing the button is combined with the bubblestream model. Although there are no movable characters, pressing the bug to its breaking point becomes engaging and expressive. The sound feedback in this sketch has a crucial function since it completes and gives sense to the whole interaction. A compound breaking and squeezing sound is obtained by sequencing at a certain threshold an impact sound suddenly followed by a bubblestream. The sensing exploits the high non-linearity of the textile resistor, placed under the bug, which requires at each interaction a variable effort. In addition, the softness of the textile sensor enhances the haptic experience, with a full integration of visual, auditory and tactile channels. The manipulative strategy is clearly expressive and the effects are directly revealed. The sound design enhances the authenticity of the sketch, by *cartoonifying* the splattering process. Indeed the sound feedback is exaggerated in order to overcome the static visual appearance of the scene.

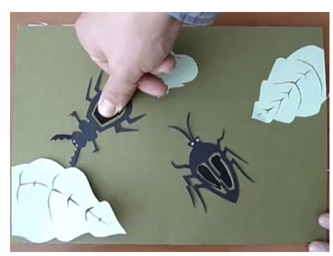

Figure 6. Squish. Pressing the bug produces a layered impact and bubblestream sound, a compound splattering event.

Team 5: Wake up Chiara! [Alberto Boem, Daniele Galante, Maddalena Mometti, and Mattia Piovani]: In figure 7, the reader wakes up a female character (Chiara), by playing a melody on a metallophone. The narration originated from the basic assignment of coupling the action of "sliding the character" with the impact sound model. As the reader slides and pushes the mallet along the keyboard, the head of the character moves up and down causing the opening and closing of the eyes until Chiara wakes up. This sketch is an example of how the connection of two mechanisms, namely a slider and a wheel, results in strong effects. The handle is expressively and tightly coupled with notes on the metallophone, while results loosely coupled with the eye movements of the character. The causality between control and display is cognitively understood (the reaction of the character to musical notes played by the reader while sliding the mallet), but the disconnected physical nature gives a sense of the magical. The overall mechanism is an example of extended movable.

Figure 7. Wake up Chiara! As the user moves the mallet left and right, a character rises up and opens her eyes.

Magic in the design of pop-up interfaces
In interactive books, the connection between control and display allows designers to explore a range that goes from enaction to magic. This property was well known in the golden age of movable books when pull-the-tab mechanisms were often used to trigger a cascade of surprising events, such as the emergence of a previously unseen character. At this level the techniques used in books bear close resemblance to the spectacular and surprising effects used in cinema since its origin [15]. Well-engineered paper mechanisms can convey a sense of magic, especially when the locus of gestural action is displaced from the main display of the consequences of such action. In other words, the hidden mechanism can make the connection between control and display more loose, thus giving the impression of a degree of autonomy in the moving part. As the complexity of mechanical linkages increases, the perceived correlation between continuous actions and their effects decreases, giving more room for the user to create interpretive and imagined connections.

CONCLUSION
In working with the paper medium along with `Arduino`, the `Sound Design Toolkit` and simple sensors, students were able to quickly build mechanical and electronically responsive interactive experiences. They were able to focus on the narrative and design as opposed to technical functionality. The medium allowed each interface to have a completely different look, texture, tone and interaction, creating unique and highly expressive and aesthetically functional interfaces. Augmenting movables with sound adds an inherently expressive dimension to a product, the pop-up book, which is by definition multi-sensory and highly interactive. Logic of display and storytelling take advantage by the time-bounded quality of sound that is exploited to pace the rhythm of narration and overall experience. Interactive and dynamic control of sound models makes potentially each manipulation a unique exploration. Each "reading" through expressive manipulation is negotiated by the reader's mood and state of mind, thus placing pop-up books at a deep level of intimacy. It would be interesting to explore how a same movable may feed back different emotions or moods depending on the intentional manipulation of the reader. It would be also interesting to study what is the degree of permanency of an augmented pop-up book over time in one's everyday life. Pop-up books are inherently affective interfaces, may augmented pop-up books be good technologies for everyday life? [18].

CONTACT INFORMATION
S. Delle Monache and D. Rocchesso: IUAV University of Venice, Dorsoduro 2206 - 30123, Venice, Italy. J. Qi and L. Buechley: MIT Media Lab, High-Low Tech Group, 77 Massachussets Ave, Cambridge, MA 02139. A. De Götzen: University of Padova - DEI, Via Ognissanti 72, 35129 Padova, Italy. Dario Cestaro: http://www.dariocestaro.it/ .

REFERENCES
1. J. F. Augoyard. *Sonic Experience - A Guide to Everyday Sounds*. McGill-Queen's University Press, 2006.
2. M. Back and D. Des. Micro-narratives in sound design: Context, character and caricature. In *Proc. Int. Conf. on Auditory Display*, Palo Alto, CA, 1996.
3. J. Backman and T. Dragwidge. Improving piezoelectric speakers with feedback. In *Audio Engineering Society Convention 106*, 5 1999.
4. L. Buechley, S. Hendrix, and M. Eisenberg. Paints, paper, and programs: first steps toward the computational sketchbook. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction, (Cambridge, UK)*, TEI '09, pages 9–12, New York, NY, 2009. ACM.
5. D. A. Carter. *White Noise*. Little Simon, 2009.
6. D. A. Carter and J. Diaz. *The Elements of Pop-Up*. Little Simon, 1999.
7. M. Chu, J. Hargreaves, and C. L. of Ornithology. *Birdscapes: A Pop-Up Celebration of Bird Songs in Stereo Sound*. Chronicle Books, 2008.
8. M. Coelho. Programming the material world – a proposition for the application and design of transitive materials. In *Proc. of the International Conference on Ubiquitous Computing (UbiComp)*, Innsbruck, Austria, 2007.
9. M. Coelho, L. Hall, J. Berzowska, and P. Maes. Pulp-based computing: a framework for building computers out of paper. In *Proceedings of the 27th international conference on Human factors in computing systems, extended abstracts, (Boston, MA)*, CHI EA '09, pages 3527–3528, New York, NY, 2009. ACM.

10. P. Cook. Principles for designing computer music controllers. In *ACM CHI Workshop in New Interfaces for Musical Expression*, Seattle, WA, 2001.

11. P. Dalsgaard and L. K. Hansen. Performing perception - staging aesthetics of interaction. *ACM Trans. Comput.-Hum. Interact.*, 15:13:1–13:33, December 2008.

12. A. De Götzen and D. Rocchesso. Continuous sonic interaction in books for children. In *International Workshop on Auditory Displays for Mobile Context-Aware Systems*, Munich, Germany, 2005.

13. S. Delle Monache, D. Hug, and C. Erkut. Basic exploration of narration and performativity for sounding interactive commodities. In R. Nordahl, S. Serafin, F. Fontana, and S. Brewster, editors, *Haptic and Audio Interaction Design*, volume 6306 of *Lecture Notes in Computer Science*, pages 65–74. Springer Berlin / Heidelberg, 2010.

14. S. Delle Monache, P. Polotti, and D. Rocchesso. A toolkit for explorations in sonic interaction design. In *Proceedings of the 5th Audio Mostly Conference: A Conference on Interaction with Sound*, AM '10, pages 1:1–1:7, New York, NY, USA, 2010. ACM.

15. E. Faden. Movables, movies, mobility: Nineteenth-century looking and reading. *Early Popular Visual Culture*, 5(1):71–89, 2007.

16. A. Farnell. *Designing Sound*. MIT Press, Cambridge, MA, 2010.

17. N. Freed, J. Qi, A. Setapen, C. Breazeal, L. Buechley, and H. Raffle. Sticking together: handcrafting personalized communication interfaces. In *Proceedings of the 10th International Conference on Interaction Design and Children, (Ann Arbor, Michigan)*, IDC '11, pages 238–241, New York, NY, 2011. ACM.

18. W. Gaver. Cultural commentators: Non-native interpretations as resources for polyphonic assessment. *International Journal of Human-Computer Studies*, 65(4):292 – 305, 2007.

19. W. W. Gaver. What in the world do we hear? An ecological approach to auditory event perception. *Ecological Psychology*, 5:1–29, 1993.

20. A. Glassner. Interactive pop-up card design. Technical report, Miscrosoft Research, 1998.

21. S. Hendrix, M. Eisenberg, et al. Computer-assisted pop-up design for children: computationally enriched paper engineering. *Advanced Technology for Learning*, 3(2):119–127, 2006.

22. D. Hug. Genie in a bottle: Object-sound reconfigurations for interactive commodities. In *Proc. Audiomostly, 3rd Conference on Interaction With Sound*, Piteå, Sweden, 2008.

23. D. Hug. Towards a hermeneutics and typology of sound for interactive commodities. In *Proceedings of the CHI 2008 Workshop on Sonic Interaction Design*, Florence, Italy, 2008.

24. R. Koehly, D. Curtil, and M. M. Wanderley. Paper FSRs and latex/fabric traction sensors: methods for the development of home-made touch sensors. In *Proceedings of the 2006 conference on New interfaces for musical expression*, NIME '06, pages 230–233, Paris, France, 2006. IRCAM.

25. S. Okamura and T. Igarashi. An interface for assisting the design and production of pop-up card. In *Smart Graphics*, pages 68–78. Springer, 2009.

26. H. Perner-Wilson, L. Buechley, and M. Satomi. Handcrafting textile interfaces from a kit-of-no-parts. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction, (Funchal, Portugal)*, TEI '11, pages 61–68, New York, NY, 2011. ACM.

27. J. Qi and L. Buechley. Electronic popables: exploring paper-based computing through an interactive pop-up book. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction, (Cambridge, MA)*, TEI '10, pages 121–128, New York, NY, 2010. ACM.

28. S. Reeves, S. Benford, C. O'Malley, and M. Fraser. Designing the spectator experience. In *Proceedings of the SIGCHI conference on Human factors in computing systems (Portland, OR)*, CHI '05, pages 741–750, New York, NY, 2005. ACM.

29. D. Rocchesso and S. Delle Monache. Spatio-temporal unfolding of sound sequences. In *Proc. Sound and Music Computing Conference*, 2011.

30. D. Rocchesso, P. Polotti, and S. Delle Monache. Designing continuous sonic interaction. *International Journal of Design*, 3(3), December 2009.

31. G. Saul, C. Xu, and M. Gross. Interactive paper devices: end-user design & fabrication. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, pages 205–212. ACM, 2010.

32. B. Verplank. Interaction design sketchbook. Unpublished paper for CCRMA course Music 250a, 2003.

33. B. Verplank, C. Sapp, and M. Mathews. A course on controllers. In *Proceedings of the 2001 conference on New interfaces for musical expression (Seattle, WA)*, NIME '01, pages 1–4, Singapore, 2001. National University of Singapore.

34. B. G. Winder, S. P. Magleby, and L. L. Howell. Kinematic representations of pop-up paper mechanisms. *Journal of Mechanisms and Robotics*, 1(2):021009, 2009.