The Laptop Accordion

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Figure 1: Is it a laptop, or an accordion?

ABSTRACT

The "Laptop Accordion" co-opts the commodity laptop computer to craft an expressive, whimsical accordion-like instrument. It utilizes the opening and closing of the laptop screen as a physical metaphor for accordion bellows, and the laptop keyboard as a musical buttonboard. Motion is tracked using the laptop camera via optical flow and mapped to continuous control over dynamics, while the sound is generated in real-time. The instrument uses both skeuomorphic and abstract onscreen graphics which further reinforce the core mechanics of "squeezebox" instruments. The Laptop Accordion provides several game modes, while overall offering an unconventional aesthetic experience in music making.

Author Keywords

NIME, interaction design, consumer hardware

ACM Classification

[Human-centered computing] Interaction design
[Applied computing] Sound and music computing

1. INTRODUCTION

Historically, electronic musical interfaces have appropriated existing hardware in unexpected but expressive ways. By exploring interactive elements on traditional musical instruments and imagining their possible analogues on commodity hardware, we can take advantage of existing musical gestures and potentially recontextualize them. Designing for widely-available computing devices benefits from a low barrier to entry (in terms of cost and experience) and familiarity to the user, as well as new aesthetic and expressive possibilities. These motivations led to the Laptop Accordion (LA), which takes advantage of the simple opening-and-closing action of nearly every modern laptop, utilizing its front-facing camera as a primary input to the interface. The interactions associated with the traditional instrument are transferred to the digital artifact, combining a recognizable instrument with an everyday computing device and resulting in a whimsical, unconventional musical interface.

Given the simplicity of the idea, the ubiquitousness of laptops, the proliferation of laptop orchestras, and the physical similarity of opening and closing a laptop to that of an ac-

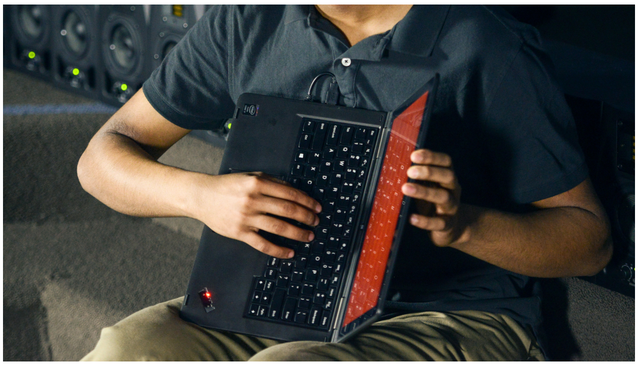

Figure 2: The Laptop Accordion (LA) tracks the opening and closing of the laptop screen as a physical metaphor for the stretching and compression of accordion bellows and the keyboard as a buttonboard. These inputs are mapped to real-time generated audio.

cordion bellow, it is surprising to us that this idea has not been implemented (or at least documented) before. (For better or for worse, it seems somebody should have made a laptop accordion by now!) As Perry Cook pointed out, "existing instruments suggest new controllers" [1]. Furthermore, the ethos of musical design for the physical laptop is well documented by Fiebrink et al. [2], and can be extended to the approach of designing "backwards" from the device in what Ge Wang calls "inside-out" design [3], as exemplified by physical mobile-phone instruments like the iPhone "Ocarina."

The LA draws from such systems of thinking about music interaction design, setting aside the all-too-familiar physical paradigms of the laptop—a user sitting in front of their laptop as terminal and display—and (literally) turns this notion on its side. The LA asks its user to rotate the laptop 90 degrees, face the screen away, hold it in a specific manner, and engage with it on uncannily familiar physical terms. As such, the laptop is recast into something else: a strange-yet-familiar, whimsical musical interface.

Facing the screen and keyboard away from the user suggests new forms of interaction (particularly with an "audience," rather than the typical one-screen-one-user paradigm) and UI challenges. Discussions of new musical interfaces often question the traditional laptop-based performance setup where a performer faces the audience with a laptop in front of them, engrossed in the information on the screen. A time-honored complaint about this performance aesthetic is that the performer looks as though they "might as well be checking their email" rather than actively participating in music creation. Furthermore, traditional DAW-based production environments have become so ubiquitous that the notion of a laptop as a physical instrument rather than a software interface, sequencer, synthesizer, or processor of musical data can be difficult to conceive. This nearly unshakable stereotypical role of the laptop is what renders the LA a compelling exercise in interaction design.

NIME'16, July 11-15, 2016, Griffith University, Brisbane, Australia.
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2. RELATED WORK

The design for the LA was inspired by previous notable reappropriations of the physical laptop for musical expression. The Small Musically Expressive Laptop Toolkit (SMELT), for instance, provides tools for developers to use the physical interfaces of the laptop as controllers, including the keyboard, microphone, and for those laptops with sudden motion sensors, the accelerometer [2]. In this work, Fiebrink et al. articulated an ethos of co-opting laptop hardware to transform the laptop into physical musical interfaces ("don't forget the laptop!"), and directly influenced the use of a laptop hinge as a physical vehicle of expression. In a less physical sense, live coding [4, 5] has re-examined the aesthetics of live laptop performance.

The iPhone "Ocarina" [3] was designed almost purely by working backwards from the available sensors and capabilities on a smartphone, leveraging multitouch, accelerometers, microphone, graphics, sound synthesis, and even networking and global positioning to craft a coherent musical artifact. It made for an uncanny computer-mediated re-envisioning of a real-world instrument.

As an augmented musical interface, Cook and Lieder's SqueezeVox [6, 7] provided additional context for an accordion-style music controller. This notable set of computer-mediated controllers didn't so much co-opt the laptop, but the accordion itself by augmenting it with various sensors mapped to synthesis parameters. The SqueezeVox project featured multiple instruments (named Bart, Lisa, Maggie, and Santa's Little Helper) that explored using the physical accordion interactions as a controller for singing synthesis.

The game modes of the LA, meanwhile, took direct inspiration from the expressive and proactive interaction paradigms in music games like Smule's "Magic Piano" [8] and, to a lesser extent, from the more reaction-based mappings of video games like Guitar Hero [9] and Rock Band [10]. The ability to play a complex song with one's own pacing (such as in Magic Piano) is a design goal that was factored into the LA, where different difficulty levels afford a low barrier of entry as well as a high skill ceiling.

Finally, the laptop orchestra paradigm has further proliferated the design of laptop-based musical interfaces [11], and provides an ecosystem for continued development and performance with the laptop [12, 13, 14].

3. DESIGN

The core mechanic at the center of the LA is the use of the laptop hinge to simulate bellow movement, and the keyboard as a stand-in for the right-hand manual. The opening and closing of the laptop screen is tracked in real-time by computer vision analysis and motivated many design decisions in creating the instrument. A primary goal was to tap into the user's notion for the action of an accordion (whether based on prior experience with the instrument or a passing familiarity) to minimize the learning curve.

A user familiar with the interaction of an accordion can use the same gestures on the LA and expect a similar result. For users with no conception of an accordion, a brief experimentation with the keys and screen rotation provides an understanding of how to control its main musical parameters, dynamics and pitch, as well as the expressive and mechanical capabilities of the instrument, including polyphony and using the keys or bellows to create different articulations, staccato or legato, just as would be the case with a traditional acoustic accordion. Since the physicality is preserved, one can experiement with LA in the same manner as the "real thing".

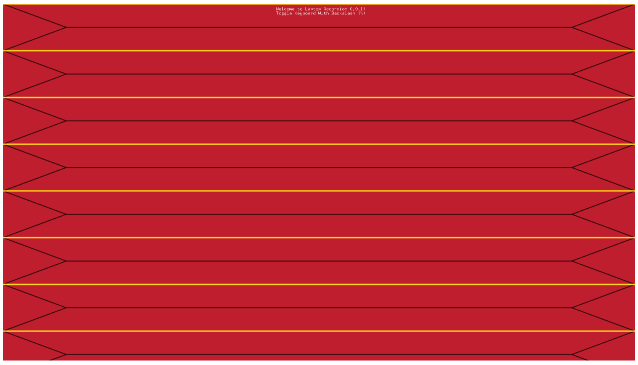

Figure 3: Skeuomorphic bellows design.

Upon beginning the program, the laptop screen renders a skeuomorphic representation of accordion bellows that stretch and compress when the screen rotates or there is movement in front of the camera. In this context, skeuomorphism refers to design cues that imitate the original instrument, but are no longer "necessary" to perform the task of sound production—whereas bellows are mechanically fundamental in acoustic accordions, the LA simply utilizes the image of bellows to refer to the original functionality of the instrument and as a vehicle for visual communication. The immediate feedback provided by this skeuomorphic system clues the user into the usage of the instrument without explicit directions, leaving them to explore the accordion on their own terms.

As a tool for encouraging user engagement with the program, skeuomorphism ties the virtual and the real accordions together, creating a meaningful metaphor for beginners without being explicit about the intended method of playing the instrument. Secondly, the orientation of the bellows on the screen (stretching and compressing along the height) suggests a particular orientation of the laptop which is more consistent with how one would hold an actual accordion, rather than sitting on a table or lap.

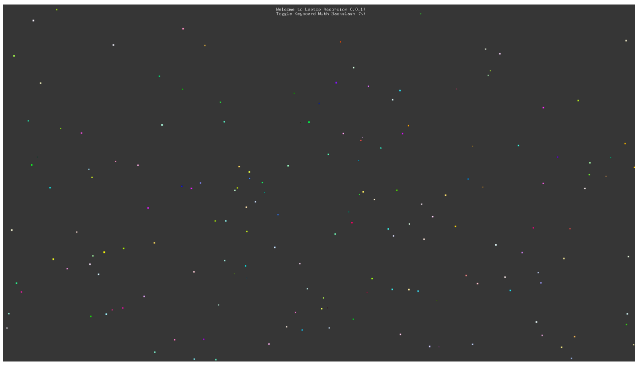

Figure 4: Alternate, non-skeuomorphic design.

A second visual style was created as an experimental, non-skeuomorphic alternative to the accordion bellows, while still retaining the graphical motion cues from before. In particular, the graphics are comprised of a field of particles on a dark background that stretch and compress at the same rate as the skeuomorphic accordion bellows. The intention of this mode was to provide similar feedback for the motion of the instrument without harkening back to the original instrument, allowing for a different relationship between the synthesis of accordion sounds and the associations these alternative visuals might suggest.

Furthermore, an overlay interface gives visual feedback of the keys being pressed (the basis for various game modes) and allows selection of various musical parameters such as scale, key, and pitch bend, as well as program parameters, such as graphical style, fullscreen toggling, game mode switching, and the pitch mapping layout.

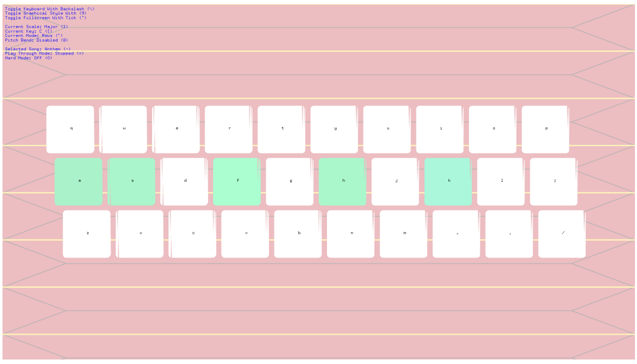

Figure 5: Keyboard overlay in "Free Play" mode.

A laptop's keyboard is congruent with a typical "button-board" arrangement on an accordion-like instrument, but as an input to a digital instrument affords easy reprogrammability of scales or other functionality. Traditional accordions are, of course, limited to the notes they were constructed to play, such as a diatonic scale in a single key. In its default state, the LA matches this capability, but the digital nature of the instrument means that it can be extended for a wide variety of musical styles. For example, playing along with an ensemble can be simplified for a beginning user by matching the key and limiting notes to a pentatonic scale, but an advanced player could utilize the full chromatic keyboard, simply by remapping the keys.

In addition to the construction of the instrument and interfaces, three modes of play were implemented in order to afford varying levels of skill and musical output control. (1) Free play mode is the most similar to playing an actual accordion. In this case, the keyboard is simply mapped to the scale and key of the user's choice, and the output pitches directly correspond to the keys pressed while moving the bellows. (2) Play through mode, by contrast, disregards the configured key mapping, instead stepping through the MIDI notes of a particular song, where any key press advances the state to the next group of contemporaneous notes. The durations of notes correspond solely to the length of each key press, from key down to key up. (3) Finally, hard mode is functionally equivalent to play through mode, but requires users to step through a song by pressing a particular key, indicated to the user in an interface reminiscent of games like Guitar Hero.

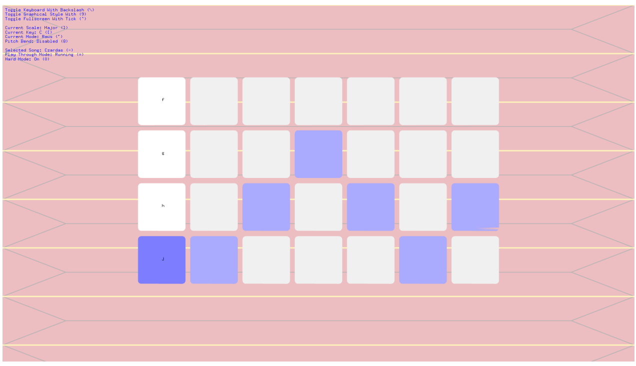

Figure 6: Laptop Accordion "Hard Mode."

4. IMPLEMENTATION

As with an acoustic accordion, sound production is primarily contingent on two parameters: volume is controlled by the rate at which the bellows are stretched and compressed, and pitch is controlled by the buttonboard. These both have corresponding mappings to the laptop itself, where bellows rate is congruent with screen rotation rate and the buttonboard is functionally identical to a keyboard.

Keeping with our interactive design goals, the sound output of the instrument is a synthesized accordion, implemented with SoundFont synthesis and MIDI controls using the Fluidsynth library. The use of SoundFonts provided acceptable real-time timbres while abstracting away many complexities in sound production, allowing us to focus on playability.

The main technical challenge of the LA is calculating a good measure of screen rotation, which is accomplished using the front-facing camera. The application is built within the OpenFrameworks library, and utilizes a built-in OpenCV (computer vision) add-on as well as a user-created add-on, OfxCv. Together, these implement feature extraction and the tracking of an input image to calculate its optical flow, or the movement of image pixels between two frames.

The OfxCv add-on utilizes an implementation of the Lucas-Kanade algorithm for estimating optical flow [15]. Using a recursively-built pyramidal representation of two successive images, the algorithm approximates vector displacements between tracked feature points, whose average is a good predictor of motion in front of the camera, or, in the LA case, the movement of the camera itself. Using optical flow for musical input can be traced to projects such as *SoFA*, which used optical flow to detect facial movement [16]. Useful overviews of these algorithms can be found in [17, 18].

As a brief technical note, the feature extraction step is not strictly necessary, and algorithms [19] exist to compute the so-called "dense optical flow," taking into account the movement of *all* pixels between images. Considering all points has the potential to offer more accurate estimates of camera motion, but in practice we found these procedures to be insufficiently performant on many laptops, while the chosen algorithm, which considers only extracted feature points, seems to offer a good blend of performance and accuracy.

The calculated velocity vector (with some conditioning) controls the MIDI channel velocity, which is congruent to the compression rate of an accordion's bellows. Given the goal of utilizing only sensors found on a typical laptop, this calculation does not rely upon any external or non-standard components.

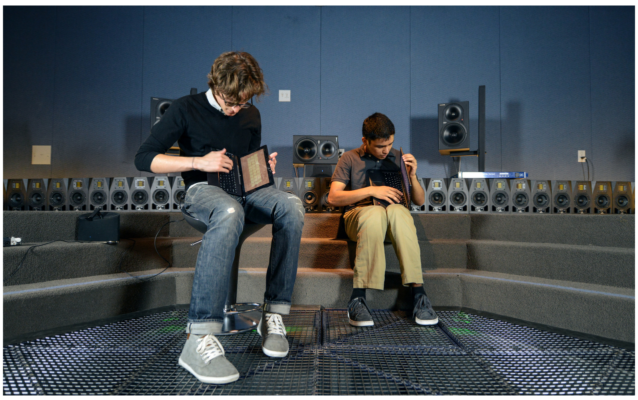

Figure 7: Laptop Accordion duo performance.

5. EVALUATION

The LA can be evaluated just as any new musical instrument, since at its core it is a translation of an actual accordion. Since squeezebox-style instruments are already well-defined, the success of the LA can be gauged by its emulation of the intrinsic musical affordances of those instruments, as well as the presence of any new expressive affordances. As with a typical musical controller, qualities of a useful invention include versatility, expressiveness, learnability, and the intangible traits that result from the idiosyncrasy of the instrument.

Since the target platform for the LA is unspecified consumer hardware, its responsiveness is subject to hardware specifications, the calculation of optical flow, and operating system latency, all of which may vary across systems. Two specific metrics we found to be important were keyboard latency and any bounds on simultaneous keypresses. Overcoming these limitations would be a primary step in developing virtuosity on the instrument. Furthermore, while the physical keyboard layout is fixed and optimized for typing, it is trivial to arbitrarily program keys to with respect to scales, keys, or other novel pitch mappings.

Using optical flow to track the opening and closing of the laptop introduces some latency, which we estimate to be in the 100 to 200 millisecond range. Fortunately, the latency of this component, with proper filtering, is less impactful than the keyboard latency, which accounts for the primary point of articulation in the sound and is far more responsive (as a matter of hardware and software design).

Optical flow, in essence, controls the volume envelope: when the laptop screen is in motion, the user would still need to press a key to begin the sound. The envelope value at the point of articulation controls a note's velocity, and subsequently provides continuous control to further modulate the volume, making a variety of nuance possible. In our informal user trials, participants report the main bellow-and-buttonboard interaction to be natural and responsive.

The physical resistance of the screen hinge emulates the feedback from air compression in traditional accordion bellows, and presents an interesting opportunity to enhance the perceived embodiment of the instrument. At the same time, a practical question remains on structural wear-and-tear of the laptop screen hinge under the stress of repeated opening and closing. While this hasn't caused issues in our experiments, one should be mindful of the possibility.

Our existing repertoire of LA music includes *The Star-Spangled Banner*, *Auld Lang Syne*, Erik Satie's *Gymnopédies*, Bach's *G Major Cello Suite*, Vittorio Monti's *Czardas*, Claude Debussy's *Clair de Lune*, Nikolai Rimsky-Korsakov's *Scheherazade*, Mozart's *Rondo Alla Turca* (the "Turkish March"), and the ever-popular *Twinkle Twinkle Little Star*. The flexibility of the instrument means that the sky is the limit when it comes to play through mode—any tune that lends itself to arrangement on the accordion can be translated into a MIDI file and played with ease.

Performance with the LA is a largely unexplored arena, but the possibility of novel performance practices was apparent during the development of the instrument. In particular, since the camera tracks whatever features it sees, waving a hand in front of the camera can be congruous to opening and closing the laptop lid. Other actions, such as moving in space or rotating one's body provide similar input, opening up a multitude of performance opportunities, as well as suggesting the LA equivalent of a "palm mute" gesture, where the camera is purposefully covered to prevent unwanted motion detection.

Finally, the LA seems to be accessible for new users, while providing a significant skill ceiling for those who wish to practice its various modes; a series of carefully-designed visual cues, for instance, teaches the instrument's mechanics. This range of difficulty can be adjusted between simplicity for novices on the one hand, and on the other, sensitivity for users advanced enough to exploit it. Above all, perhaps, there is inherent charm in watching a performer hold a laptop sideways and play a tune with it.

6. FUTURE WORK

Moving forward, there are several avenues for exploration and improvement. The Laptop Accordion can benefit from more accurate simulation of the accordion sound, and experimentation with abstract (non-accordion) sounds that lend themselves to the interaction. In both cases, the instrument could become a professional tool or a more fully realized *objet d'art*. Options for improved synthesis veracity include physical modeling of the acoustic instrument or reproduction of samples from a variety of real-life instruments (such as concertinas or accordions from different time periods).

User studies would be extremely useful in determining the capabilities of the LA with respect to skeuomorphic feedback and the possibility of virtuosity. Interesting topics for study would be the preference of performers and audiences for various interfaces (skeuomorphic or not), as well as the system performance requirements to enable a virtuoso player in pushing the instrument to its limits.

Cross-platform compatibility and modularity is another distinct goal for the future, enabling more types of users to experience and iterate on the software. While the initial artifact was intended as an exercise in design, future projects could use the LA paradigm as a generalized controller for other sounds (e.g. singing synthesis, like the SqueezeVox). Options for increased modularity—in tandem with the goals for sound production—include interchangeable synthesis modules, as well as frameworks for driving other engines (e.g. via MIDI or OpenSoundControl).

On a more mechanical level, the calculation of the average optical flow is a relatively complex and expensive operation, and therefore is not very well suited to slower devices. Research into algorithms that provide good tracking with lower computational cost (and possibly lower latency), or even modifications to the current system, might extend usability to older or low-cost devices, enabling a larger userbase and the possibility of inexpensive musicianship. In addition, modification of the synthesis system (as mentioned above) could result in speed gains while lending additional flexibility in implementation.

Finally, while a range of music is currently being played on the LA, the possibilities afforded by instrument-specific works are broad and of significant interest. Considerations such as networking and ensemble play are rich for exploration, as is the use of the screen for the display of work-specific artistic content. As previously noted, laptop orchestras like Stanford's SLOrk provide an excellent incubator for the vast possibilities of the instrument. We look forward to creating dedicated works for the LA in exploring the possibilities of various ensembles.

7. CONCLUSIONS

We designed, implemented, and evaluated an accordion-like instrument based on the core components of a traditional laptop. Our efforts made use of off-the-shelf image processing algorithms to track the motion of a laptop's screen, serving as an analogue to the compression of accordion bellows, which is in turn mapped to the volume of the synthesized sound. The net result was a piece of software we found to be accessible yet nuanced for musical expression.

Moreover, by prioritizing user experience and aesthetic satisfaction in designing the Laptop Accordion, we developed an artifact that is functionally pleasing to use, and aesthetically quirky. We believe that more potential for musical expression exists in the tasteful, creative repurposing of existing technology, and we look to continuing this line of design inquiry for future work.

8. ACKNOWLEDGMENTS

We would like to thank our colleagues at CCRMA, as well as the students of the Music, Computing, Design course for additional feedback.

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