PushPull. Reflections on Building a Musical Instrument Prototype

Amelie Hinrichsen[1], Sarah-Indriyati Hardjowirogo[2], Dominik Hildebrand Marques Lopes[3] and Till Bovermann[4]

[1] Berlin University of the Arts, Berlin, Germany
a.hinrichsen@udk-berlin.de
[2] Technical University Berlin, Germany
hardjowirogo@tu-berlin.de

[3] Berlin University of the Arts, Berlin, Germany
d.hildebrandmarqueslopes@udk-berlin.de
[4] Berlin University of the Arts, Berlin, Germany
t.bovermann@udk-berlin.de

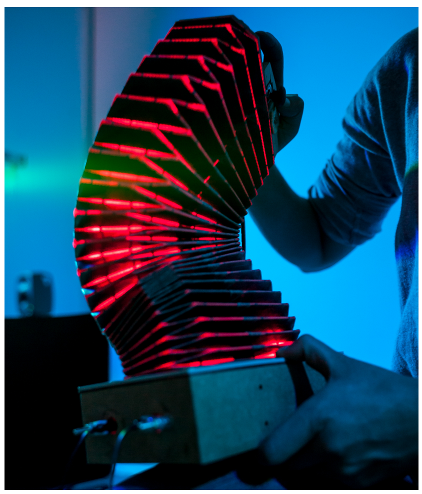

Fig. 1. PushPull during live Performance

Fig. 2. PushPull Prototype

Abstract: The "Liberation of Sound" by means of electronics, as anticipated among many others by Edgard Varèse, released musical instruments and musical instrument making from the physical constraints of sound production. At the same time, this new freedom of choice resulted in the necessity for instrument makers to explicitly reflect on questions such as: What general expectations do we have towards a contemporary instrument? Independent of its form, what and how do we want it to sound like? And, in opposition to this, detached from its sonic gestalt, what should it look like, feel like, be played like? What is it supposed to do, or not to do? Based on these questions, this paper is an interdisciplinary approach to describe requirements for, hopes in, and promises of expressive contemporary musical instruments. The basis for the presented considerations is an instrument designed and played by the authors. Over the course of the design process, the research team touched topics such as playability and mapping strategies in relation to artificially induced complexity. This complexity, as the authors believe, may serve as an alternative common ground, which substitutes originally prevalent physical constraints in instrument building.

Keywords: instrumentality, electronic musical instruments, live performance and physical interaction, instrument building, interdisciplinary research

Introduction

Today, more than ever before, the process of designing and developing a musical instrument prototype requires a large number of decisions to be made regarding almost every aspect of the intended device. While many of such decisions were formerly given through physical necessities, most prominently the causal relationship between factors like size, form, material and energy coupling as well as their influence on an instrument's sonic gestalt, these relations are now dissoluted by means of electronics and digitization. To the contemporary instrument maker, this means not only an increase of artistic freedom, as it also enforces explicit, *seemingly independent* decisions for all those aspects like its sonic and visual gestalt, its playing technique, and the choice of raw materials. Since the physical constraints have moved to the background, each of these decisions needs to be justified aesthetically: Why is the instrument supposed to look and sound exactly like this? Why does it allow exactly this sonic latitude, why does it feel exactly like that?
In the context of this paper, we argue that the dissolution of former causalities induces the establishment of new ones. Complexity can inform the design of an instrument in such a way that the resulting artefact shows qualities sufficient for expressive and dynamic playing. Using the example of the musical instrument prototype *PushPull*, we illustrate how, in the course of interface development, such continuous decision making demands the integration of considerations concerning appearance, interaction and sound production. Combining approaches from design theory and traditions of instrument building together with the above mentioned demands eventually yields instrument-specific causalities.
After introducing our concept of complexity (Section 2), we illustrate how these thoughts shaped our decisions on exterior appearance (Section 3), interaction (section 4), and sound production (Section 5). Closing, we get back to the idea of instrument-specific causalities and discuss how they are being established in the case of PushPull (Section 6).

2 Complexity as a Constituting Element of Musical Instruments

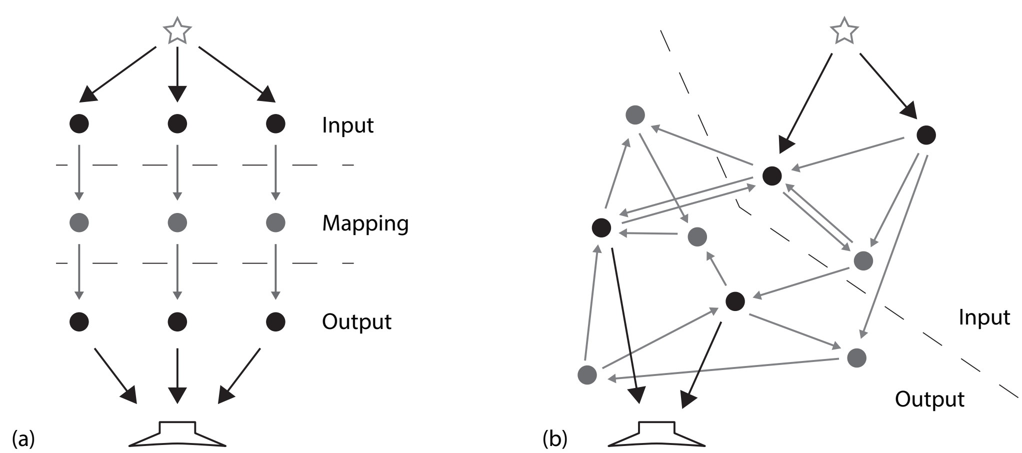

Fig.3. Instrument Structure according to Wessel (a) vs. Instrument Structure with vertical and horizontal interrelations of constraints (b). Note that the mapping in (a) remains blurred in (b) due to the introduced feedback paths.

We understand complexity as a measure of interrelations between the elements of an instrument. If there are few interrelations, the complexity is low, whereas a high amount of complexity is given when there are no recognisable borders between the modules of an instrument.
Traditional instruments, for instance, feature a high amount of complexity since they do not have a clear separation between input, mapping, and output. Rather, borders between those elements are

heavily blurred; modulating one parameter has a (non-linear, more or less audible) effect on others. Complexity is closely related to constraints of instrument elements and their horizontal and vertical interrelations. A *horizontal interrelation* of two constraints identifies limitations of a similar type, e.g. the length of a violin bow and the different bowing techniques possible at specific bow locations. In comparison, *vertical interrelations* between constraints are those limitations, which affect elements of different types, e.g. the size of an acoustic instrument and its spectral characteristics.

The "Liberation of Sound" by means of electronics released musical instruments from those physical constraints of sound production: it became possible to construct instruments from independent modules with defined communication interfaces. Vertical interrelations between constraints did not appear due to physical limitations; rather they had to be explicitly introduced.

In commercially available instrument modules, a trend towards flexibility can be observed as well: horizontal interrelations between constraints are minimized as far as possible in favour of generic interfaces (see, e.g., fader boxes, in which parameter changes can be done by moving one fader without influencing the others).

Since complexity not only contributes to the character of an instrument but also motivates the player to search for ways of expression, we think that the level of complexity serves as a measure for its artistic potential. We therefore argue that introducing constraints and interrelations between the different elements of an instrument makes the interface less random, hence enabling it to become a partner with its own identity.

Now, one might ask, why then work with electronic instruments at all? Our answer to this is that, unlike traditional instruments, digitization and electronics allow to explicitly shape the interrelations between instrument elements, thus enabling broad variation in instrument and sound designs. In the following sections we describe how these thoughts on complexity (in)formed the design of PushPull.

3 Exterior Appearance

For centuries, bellows have been used for the sound production in organs, squeezeboxes, and bagpipes, their permanent and regular airflow inevitably reminding of breathing in and out – the literal embodiment of corporeality, of life itself, as Michel Serres puts it:

> “It [the body] breathes. Breathing, both voluntary and involuntary, can take different forms, transforming itself by working like the bellows of a forge. After the piercing cry of a baby's first breath, its first sigh, the body begins to enjoy breathing, its first pleasure.” (Serres 2008, 314)

Here, the movement of the bellow serves not only as a metaphor for corporeality and liveliness, but also for the labour and effort of a blacksmith.

Bellow-like elements can also be found in more recent electronic instruments, such as the accordiatron (M. Gurevich & S. von Muehlen) or the squeezevox [sic] (P. Cook & C. Leder, both 2000). The developers of the accordiatron state in their documentation paper that they, too, found the “squeeze box [to be a] compelling starting point because of the expressive physical engagement of the performer and the subsequent value for live interaction.“ (Gurevich & von Muehlen 2000, 25) Similarly, the squeezevox has been designed with the purpose of controlling vocal sounds, so the bellows here, too, were used to control breathing in a more literal sense.[1]

Speaking of the “visual intrigue” of an instrument, they stress the importance of its exterior appearance: “A performance instrument should be interesting to watch as well as to hear, otherwise part of the purpose of live performance is lost.” (Gurevich & von Muehlen 2000, 25)

[1] *cf. http://soundlab.cs.princeton.edu/research/controllers/SqueezeVox/, 27 Oct 14*

Acknowledging as well an engaging appearance as constituting element of an instrument, we included cultural codes regarding appearance and perception when designing a new musical instrument. In the case of PushPull, the bellow, as an archetype having both a long tradition as a part of musical instruments and as a reminiscence to the blacksmith's tool, served as the central element of the setup. It met our requirements regarding affordance, while at the same time triggering enough imagination to allow for mystique associations, not only for the audience but also for the musician herself.
To create this mystique, a PushPull performance starts in total dark with just some red light emerging out of the bellows, thus attracting all attention to their movement[2]. This strong visual characteristic complements the archaic look of the black bellow made out of latex with a fine, grid-like texture. Reminding of snakeskin, this leather-like material, in combination with the wooden hand piece, turns the interface for digital sound synthesis into an object with a strong mechanical, but at the same time organic impression.
For example, once a member of the audience described his experience of the performance as some kind of "post-apocalyptical punk" concert.
Within the exterior appearance of PushPull resonates a close relationship of cultural connotations, technical requirements, materiality and playability. These aspects, influencing each other during the decision-making process, implement a complexity inherent in the instrument's gestalt.

4 Interaction

The way of interacting with the instrument plays a significant role in matters of entangling parameters. Out of a multitude of possibilities, we picked three coherent elements that we found in accordance to our complexity hypothesis described in Section 2.
According to J.J. Gibson' s Theory of Affordances (Gibson 1979), every object is equipped with certain action possibilities – affordances – that enable humans to interact with their environment. Following this thought, musical instruments, too, exhibit affordances that suggest particular modes of interaction – for example, a keyboard affords playing by pressing keys, a guitar affords strumming, etc. Creating a physical instrument, therefore, includes reflecting and creating its affordances.
As mentioned in Bovermann et. al. (...),"[c]reating an instrument [...] is not only about the interface itself but the routines and patterns merging the object with the subject". Playing an instrument requires the coaction of mental and physical processes, practicing on the instrument is said to result in a certain kind of body knowledge in so called "body schemata" (Leman 2010, 8). These memorized motor patterns, in our opinion, are decisive for intuitive and expressive playing. Because of that we wanted PushPull to allow the development of such body schemata. This can be achieved by introducing physical constraints and therefore a direct (passive) force feedback, which in turn enables the musician to develop a subliminal association between movement, force, and sound.
The aspect of physicality is often brought up as a motive for taking the effort to create an individual set-up in the context of electronic live music. During an interview, electronic musician Jeff Carey described his desire for "a physical grip on the sound":

> "Performing on stage with musicians and feeling like a piece of office furniture was unrewarding enough to push me to have a physical grip on my sounds as it seems like with those other players." (Carey 2014)

In the context of electronic live music, this physical grip has been neglected for a long time. Even though there have been several attempts to bring the body back into the performance of electronic

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[2] *In fact this quite dominant element (LED light in combination with light sensors and reflective foil on the inside of the bellow) originates from a technical requirement, which will be further described in Section 4.*

music since the early 1980s[3], the main set-up of electronic music performance in most cases still oscillates between keyboards and the office-like environment of laptops.
We therefore decided to implement complexity on the level of interaction by creating affordances, which, just as in traditional instruments, force the performer to see her interaction not only as being directly with the instrument but actually with the sound itself.
In the case of PushPull the instrument is strapped to the upper leg and being played either left- or right-handed. The fingertips reach four buttons[4] and a thumb stick, which offer further options for sound generation. Pressing one of the black buttons starts a sound process, which can be manipulated with the other control elements (thumb stick, moving the bellow). To switch between three sound engines the musician needs to press the red button together with one of the black buttons.
Putting the hand flat to the handle and securing it with the strap creates close physical contact. The movement of the bellow becomes actually a transformation of the hand's movement by reading out various values. An IMU inside the top part senses the acceleration of the hand. Light sensors within the bellow measure the distance between top and bottom part and therefore give a rough estimation of its contraction. Also there are two microphones on the bottom part pick up the airflow into and out of the valves hidden inside the instrument. The specific positioning of the sensors creates control signals that are intentionally not independent, but entangled in a variety of ways by the interface. The result is a high number of interrelations, which create mapping options that are very specific for this instrument.
Taking materiality and object behaviour into account, we established an organic link between movement and generated sound through the mapping. The natural resistance of the airflow into and out of the valves, the ubiquitous demand for effort that some consider being another premise for expressivity (e.g., cf. Croft 2007, 63f) would be fulfilled for instance. But much more important: Because many of the interactions are not clear gestures with obvious names, the setup invites to develop implicit knowledge or intuition about how to shape the sound.

5 Sound Production

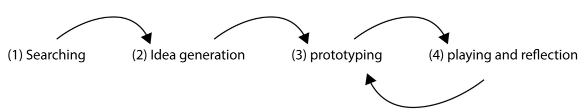

Fig. 4. Structure of the Design Process

As described in Section 2, computation allows disentangling energy coupling. However, it can also help to form networks where sound generation and control fuse into each other, creating complex functionality. This does not necessarily result in behaviour comparable to traditional instruments; rather it may form a gestalt with no counterpart in the physical realm. Without this counterpart, there is no preeminent model of interaction with the constituting elements of sound creation. In order to be able to form such models by emphasising inner and outer relations between object behaviour, interaction, and sound generation, we did not start programming until having the first working hardware artefact at hand. Sound patches are developed within loops of creating code, playing the instrument, observing,

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[3] *The 1980s and 1990s saw a huge variety of more or less experimental wearable interfaces being developed, many of them glove-shaped (e.g., The Hands by STEIM's Michel Waisvisz (1984), Laetitia Sonami's famous Lady's Glove (1991) and their commercially sold counterparts, such as VPL's DataGlove, Mattel's PowerGlove and the Exos Dexterous Hand Master, the latter three being compared in a 1990's article tellingly entitled "Reach out and Touch Your Data" [Eglowstein 1990]), others resembling futuristic jumpsuits, like Yamaha's Miburi (1996), others again exploring the musical potential of the entire wardrobe, such as the diverse developments of MIT's Media Lab, most prominently the Dance Sneakers and the Musical Jacket (both 1997).*

[4] *one red button and three black ones*

reflecting, and adjusting the existing constraints and interrelations (see fig.4). The possibility to use the two microphone input signals as control input for digital sound processes ends up with quite simple sound patches but turned out to be capable of producing a unique musical outcome linking digital sound processes closely to the physical artefact.

As an example for instrument-specific design options we describe one sound patch in detail. The breathing-sound is created by routing the two microphone-inputs, which capture the noisy airflow turbulences, into band-pass filters. The filter frequencies are controlled by hand-movement (e.g. pitch and roll). This movement is sensed by an inertial measurement unit[5] mentioned already in Section 4 that provides information about acceleration and orientation of the hand in three dimensions. The resulting sounds can range from small and short rhythmical structures to slowly moving wind-like soundscapes with high dynamic. After some practice, one is able to handle the latency and damping of energy transfer mainly introduced by the bellow's force feedback, quite well. Accurate playing in time and with a defined intensity is thus a matter of human capabilities.

In terms of the sound characteristic of the instrument, we differentiate between interrelations that include physical elements (e.g. sensors, speakers or materiality) and interrelations that consist solely of digital parts. While e.g. the actual positioning of sensors in the physical artefact constitutes a fixed correlation and therefore establishes an (object-)specific sonic character, in the purely digital case it is possible to inject dynamical structures allowing to adjust inter-element relations at will. When aiming for a complex instrument with many elements involved, in the digital realm one can decide for each element to be either static or accessible on the fly, e.g. during performance. In modern digital sound synthesis patches the number of elements that are probably worth performing can easily exceed the number of available interface elements. A further given fact is the finite amount of elements that can be consciously and bodily controlled in parallel by a human. Deciding an element to be performable requires the definition of value ranges and mapping functions, where the possibilities to do so within a highly complex and multidimensional parameter space are hard to grasp.

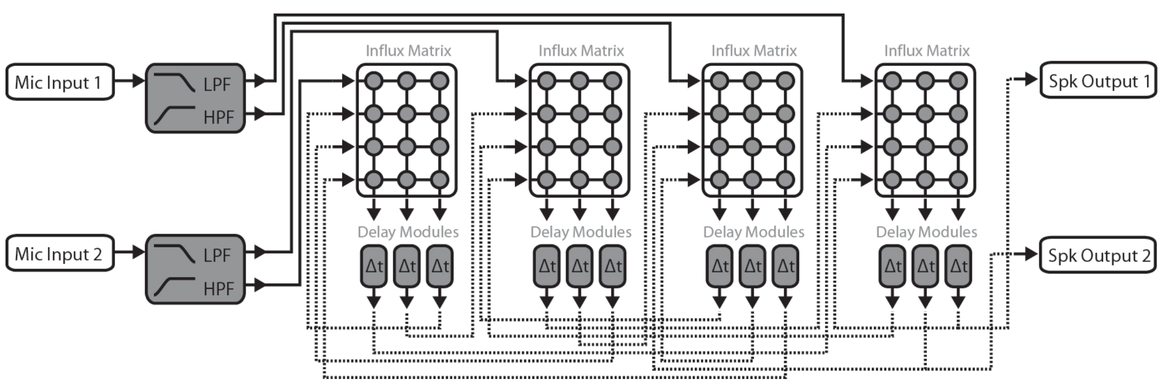

Fig. 5. Influx Patch used in PushPull

Reconfiguring inner functionality in order to explore possibilities of mapping can become an interesting musical live practice by itself (see fig. 5). It shows a patch where one cannot find any digital sound generators. Instead, the constituting input parts, two microphones and three sensors, get randomly (re-) connected and (re-) scaled on demand by pressing a button. Influx (de Campo 2014) as one central element provides highly flexible mix matrices to form linear combinations of

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[5] *As mentioned in Section 4 an IMU attached to the top part tracks the hands acceleration. Furthermore, the bottom part hosts an Arduino for serial communication and two microphones. The valves inside the bottom part guide the air through one of the two outlets. One is dedicated for air output (bellow contraction), whereas the other is an air inlet (bellow expansion).*

inputs and outputs. The matrices and some filter and delay modules mark the fundamental software parts. Delayed outputs feed back into matrix inputs, introducing complexity in form of memory. Using the bellow to provoke the system from outside can result in drastic soundscapes, ranging from thunder-like noise structures to tonal sounds with complex harmonic spectra evolving over time. The system tends to either explode, to reach timbral stability, or to fall in silence. Global parameters that influence e.g. all delays, can be controlled by hand movement. This control differs with each new set of connections. The instrument provokes a form of music making that is not comparable to playing traditional instruments; rather, it is an artistic research in the field of second order cybernetics[6] in music: the instrument creates ever new sets that form non trivial behaviour evolving over time. This behaviour is a result of inner and outer complexity of the artefact. One can observe and trigger this behaviour through interaction in terms of movement. This causes the system to be irritated, in our case not only in a metaphorical sense, by confronting the system with turbulences. The observation process is not objective. Artefact and observer, instrument and player, are connected in a circular manner. The observer is a constituting factor of the system. Taking this into account, she has to observe her process of observation, namely her interaction. While this circularity may be seen as common in a design process, performing live in that sense may result in interesting shifts in common performance ecology:

One cannot plan far into the future, because one does not know how the instrument will behave.

One can only get an idea about the closer future by active listening to the instrument.

This way music making is about finding interesting correlations of movement and sound instead of implementing them beforehand.

6 Conclusion

In this paper, we presented the process of designing and building PushPull, a hybrid musical instrument prototype based on the bellow as a physical interface. We described how complexity was implemented on all levels we found relevant for the creation of an instrumental identity or gestalt and how this required continuous decision-making, which we showed to be based on an assemblage of considerations, associations, and convictions of the most different kinds.

As outlined at the beginning, we argued that, in the case of electronic musical instruments, the dissolution of former causalities might induce the establishment of new ones. Now that the once necessary union of sound generation and control in one device has become as much an option as the correlation between material and sound, between playing action and resulting sound, it falls to the instrument maker to define instrument-specific causalities every step of the way. This is to say that once an instrument does not sound like it does because it has this particular shape or is made from this particular material, the instrument maker has to decide why her instrument will sound like it does. Her justification will most probably not be a physical, but rather a conceptual one. If she is to say why she chose this particular playing technique, she will most likely argue a specific movement, a promising interface model, or a player already experienced in an existing technique, and not with the length of strings or air columns. Similarly, the choice of a particular material will only rarely have to do with its resonance quality, but at most with its durability and its aesthetic value.

What can be observed here is a shift from physical necessities to aesthetic decisions. Instrument making no longer is a playful illustration of physical laws, but rather resembles a decision tree; a decision tree with its root coming from complexity, which is meant to be inherent in all constituting elements of the instrument.

While some of the new causalities are suggested by specifics of the evolving instrument, others are more about individual choices. In either case, they are a central part of instrument design and

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[6] *A good overview about second order cybernetics by Ranulph Glanville can be found at http://www.facstaff.bucknell.edu/jvt002/BrainMind/Readings/SecondOrderCybernetics.pdf, 29 Oct 2014 mentioning Heinz von Foerster, Luhmann and others.*

absolutely worth of reflective deliberation.
Yet, there is one universal causality that we became acquainted with during the process of designing and building PushPull and that will probably endure eternity. Sometimes, the best reason for a particular decision is just: “Because... I like it that way.”

Acknowledgements. This paper is based upon work supported by the Einstein Foundation Berlin.

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