# PUSHPULL: REFLECTIONS ON BUILDING A MUSICAL INSTRUMENT PROTOTYPE

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## ABSTRACT

The 'liberation of sound' by means of electronics, as anticipated by Edgard Varèse (1966), amongst many others, released musical instruments and musical instrument making from the physical constraints of sound production. While this may sound naïve in light of two decades of musical games and NIME, we consider it a valid and important starting point for design and research in the NIME field. This new freedom of choice required instrument makers to explicitly reflect on questions such as: what general expectations do we have of a contemporary instrument? What do we want it to sound like? And, detached from its sonic gestalt, how should the instrument look, feel and be played? What is it supposed to do, or not to do? Based on these questions, this paper is an interdisciplinary approach to describing requirements for and expectations 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 on topics such as interaction and mapping strategies in relation to what we call artificially induced complexity. This complexity, the authors believe, may serve as an alternative common ground, substituting originally prevalent physical constraints in instrument building.

## KEYWORDS

Instrumentality, Electronic Musical Instruments, Live Performance and Physical Interaction, Instrument Building, Interdisciplinary Research.

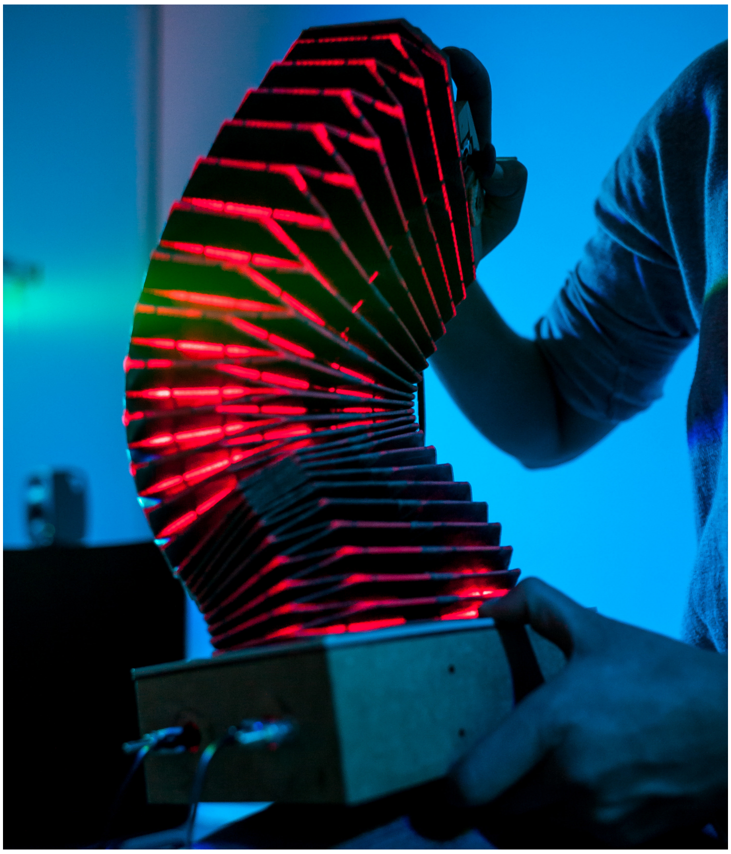

**Figure 1** PushPull during live performance.

**Figure 2** PushPull prototype.

## 1. INTRODUCTION

Today, more than ever before, the process of designing and developing a musical instrument prototype requires a large number of decisions regarding almost every aspect of the intended device. While many of such decisions were formerly dictated by physical necessities, most prominently the causal relationships between factors like size, form, material and energy coupling and their influence on an instrument's sonic gestalt, these relations are now simplified by means of electronics and digitization. To the contemporary instrument maker, this means not only an increase in artistic freedom, it also enforces explicit, *seemingly independent* decisions regarding aspects like the instrument's sonic and visual gestalt, its playing technique, and the choice of raw materials (cf. Magnusson 2009). Since the physical constraints are now much reduced, each of these decisions needs to be justified aesthetically: why is the instrument supposed to look and sound as it does? Why does it allow a particular sonic latitude, why does it feel a certain way?

In 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 bears the necessary qualities for expressive and dynamic playing. Using the example of the musical instrument prototype *PushPull*, we illustrate how, over the course of instrument 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 with the above-mentioned demands could possibly yield instrument-specific causalities.

Section 2 introduces the notion of complexity after Hunt *et al.* We then illustrate how these thoughts shaped our decisions on exterior appearance (Section 3), interaction (Section 4), and sound production (Section 5). Finally, we get back to the idea of instrument-specific causalities and discuss how they have been established in the case of PushPull (Section 6).

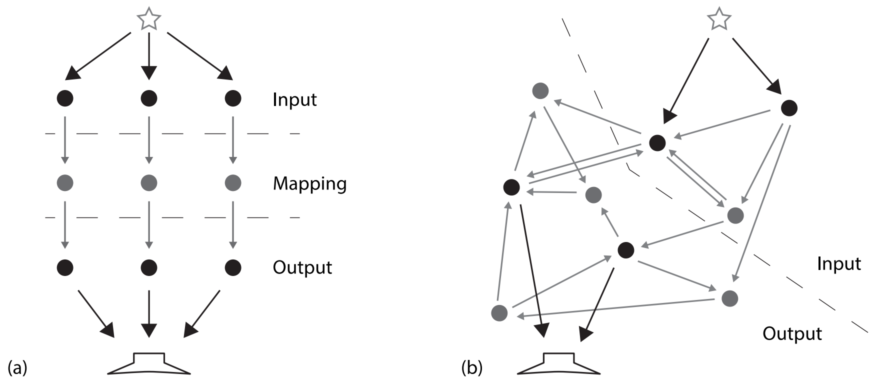


**Figure 3** Instrument structure according to (a) Wessel vs. (b) a more open structure with non-hierarchical constraints. Note that the explicit mapping shown in (a) is blurred in (b) due to system-inherent feedback.

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 degree of complexity applies when a clear separation between the modules of an instrument cannot be made, as is the case with traditional instruments. As stated by Hunt *et al.* (2000, 1),[1] traditional instruments are highly complex as they do not have a clear separation between input and output. Rather, borders between 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 refers to related limitations, e.g. the length of a violin bow and the different bowing techniques possible at specific bow locations. By comparison, *vertical interrelations* between constraints are those limitations which simultaneously 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.

A trend towards modularity can be observed among today's commercially available instrument modules : horizontal interrelations between constraints are minimized as far as possible in favour of generic interfaces (e.g. fader boxes which allow parameter changes to be made by moving one fader without influencing the others).

1. "In acoustic musical instruments the sound generation device is inseparable from the human control device, and this yields complex control relationships between human performers and their instruments." (Hunt et. al. 2000, 1)

Since complexity not only contributes to the character of an instrument but also motivates the player to search for means of expression, we propose that the level of complexity may serve as a measure of an instrument's artistic potential. We therefore argue that introducing constraints and interrelations between the different elements of an instrument makes the interface less arbitrary, hence enabling the unification of its identity.

Why, then, work with electronic instruments at all? Our answer to this is that, unlike traditional instruments, digitization and electronics allow for explicit, precise shaping of the interrelations between instrument elements, thus producing broad variation in instrument and sound designs. In the following sections, we describe how these thoughts on complexity informed the design of PushPull.

## 3. EXTERIOR APPEARANCE

For centuries, bellows have been used for sound production in organs, squeezeboxes, and bagpipes, their permanent and regular airflow inevitably visually reminiscent 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.

Furthermore, bellow-like elements can be found in more recent electronic instruments, such as the accordiatron (M. Gurevich & S. von Muehlen) and the squeezevox [sic] (P. Cook & C. Leder, both 2000). The developers of the accordiatron state in their documentation paper that they 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; in this case, the bellows are used to control breathing in a more literal sense.[2]

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)

In the case of PushPull, the bellow, as an archetype with a long tradition both as a part of musical instruments and as a reference to the blacksmith's tool, served as the central element of the setup. It met our requirements regarding modes of interaction, while at the same time triggering enough imagination to allow for 'mystic associations', not only for the audience but also for the musician herself.

2. C.f. http://soundlab.cs.princeton.edu/research/controllers/SqueezeVox/, 27 Oct 14

To create this mysticism, a PushPull performance begins in complete darkness with only some red light emerging out of the bellows, thus attracting all attention to their movement.[3] This strong visual characteristic complements the archaic look of the black latex bellow with its fine, grid-like texture. Reminiscent of snakeskin, this leather-like material, in combination with the wooden hand grip, turns the interface for digital sound synthesis into an object with a strong mechanical but, at the same time, organic appearance.

Underpinning PushPull's exterior appearance is a close relationship of cultural connotations, technical requirements, materiality and playability. These aspects, influencing each other during the decision-making process, realize the complexity inherent in the instrument's gestalt.

## 4. INTERACTION

The way of interacting with the instrument plays a significant role in matters of linking parameters. Out of a multitude of possibilities, we picked three coherent elements that we found to be 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 aid humans in their interaction with their environment. Following this thought, musical instruments exhibit affordances that suggest particular modes of interaction – for example, a keyboard affords playing by pressing keys, a guitar affords strumming, etc. Creating an instrument, therefore, includes reflecting on and creating its affordances.

As mentioned in Bovermann et. al., "creating an instrument […] is not only about the interface itself but the routines and patterns merging the object with the subject" (2014, 1638). Playing an instrument requires input from both mental and physical processes. Practising on the instrument is said to result in a certain kind of tactile knowledge or 'body schemata' (Godøy and Leman 2010, 8). These memorized motor patterns, in our opinion, are essential for intuitive and expressive playing. Therefore, 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 attempting to create an individual set-up. 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 […]."
> Carey 2014

3. 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.

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 music since the early 1980s,[4] the main set-up of electronic music performance in most cases still oscillates between keyboards and an 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, would force the performer to see her interaction not only as being in direct connection with the instrument but also with the sound itself.

In the case of PushPull, the instrument is strapped to the upper leg and played either left- or right-handed. There are four buttons,[5] one for each finger, 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). In order to switch between three sound engines, the musician has to press the red button together with one of the black buttons. The intended close physical contact was created by placing the hand flat onto the handle and securing it with the strap. Thus, the movement of the bellow becomes a transformation of the hand's movement. An inertial measurement unit inside the top part senses the acceleration of the hand. Light sensors within the bellow measure the distance between its top and base, providing a rough estimation of its contraction. Furthermore, hidden inside are two microphones on the base that pick up the airflow into and out of the valves along with an Arduino for serial communication. The specific positioning of the sensors creates control signals that are intentionally not independent but instead 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 to this instrument.

Taking materiality and object behaviour into account, we established an organic link between movement and generated sound via the mapping. For instance, the seemingly ubiquitous demand for physical effort that has been called a prerequisite for expressivity (c.f. Croft 2007, 63f) is here fulfilled by the natural resistance of the airflow in and out of the valves. But what is much more important is that many of the interactions are not clear gestures with obvious purposes and con-

4. The 1980s and 1990s saw a huge variety of somewhat 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)). Some innovations from this time resembled futuristic jumpsuits, like Yamaha's Miburi (1996), with others further 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).

5. One red and three black buttons.

sequences; instead, the setup encourages the development of implicit knowledge on how to shape the sound.

## 5. SOUND PRODUCTION

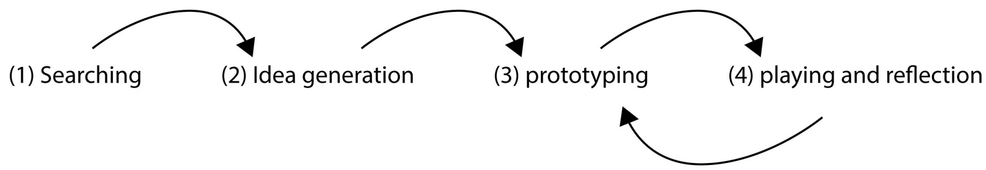


**Figure 4** Structure of the design process.

As described in Section 2, computation enables the separation of energy coupling. However, it can also help to form networks in which sound generation and control fuse into each other, creating complex functionality.[6] This does not necessarily result in behaviour comparable to that of traditional instruments; rather, it may form a gestalt with no counterpart in the physical realm. Without this counterpart, there is no existing model of interaction with the same constitutive elements of sound creation. In order to be able to form such models that emphasize inner and outer relations between object behaviour, interaction, and sound generation, we did not start programming until we first had the working hardware artefact at hand. Sound patches were developed within cycles of creating code, playing the instrument, observing, reflecting, and adjusting the existing constraints and interrelations (see Fig. 4). Using two microphone input signals as the control input for the digital sound processes meant that, by means of the close link between digital sound process and acoustic properties, even simple sound patches produced a unique and complex musical outcome.

In the following, one of the sound patches used is described in greater detail, in order to give an example of instrument-specific design options. The sound of breathing 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 movements (e.g. pitch and roll). These movements are sensed by an inertial measurement unit (see 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 slow-moving wind-like soundscapes with high dynamics. After some practice, the player 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,

6. In accordance with Hunt *et al.* (2000, 2), we understand complex mappings as a condition of musical expression: '[t]he resulting instrument's expressivity is much dependent on the specific mapping strategies employed. [...] [S]killed musicians take advantage of complex mappings.'

speakers or materiality) and interrelations that consist solely of digital parts. While, for example, the actual positioning of sensors in the physical artefact constitutes a fixed correlation and therefore establishes an (object-) specific sonic character, in the case of the purely digital, it is possible to inject dynamic structures that allow the adjustment of inter-element relations at will. When aiming for a complex instrument with many elements in the digital realm, it can be decided individually for each element whether it should remain static or be changeable on the fly, e.g. during performance. We found that the number of controllable elements of a sound patch made available to the performer could easily exceed the number of available interface elements. A further fact is the finite amount of elements that can be physically and consciously controlled in parallel by a human. Deciding that an element (e.g. an oscillator input frequency) should be changeable requires the definition of value ranges and mapping functions. In multidimensional parameter space, a playful exploration may be a promising alternative to a systematic approach. As described by de Campo (2014), these heuristics may lead to the discovery of unapparent but appealing mappings.

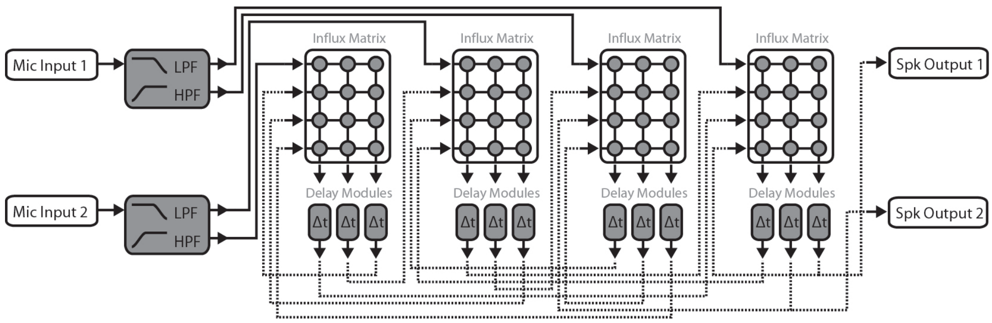


**Figure 5** Influx Patch used in PushPull

Reconfiguring inner functionality in order to explore possibilities of mapping can become an engaging musical live practice in its own right. Fig. 5, for instance, shows a patch where there are no digital sound generators to be found. Instead, the input parts (the two microphones and three sensors) are randomly (re-)connected and (re-)scaled on demand by pressing a button. The central element of influx provides highly flexible mix matrices that form linear combinations of inputs and outputs (dcf. ibd.). The matrices and some filter and delay modules comprise the fundamental software parts. Delayed outputs feed back into matrix inputs, introducing complexity in the form of memory. Using the bellow to provoke the system from the outside can result in dramatic soundscapes, ranging from thunder-like noises to tonal sounds with complex harmonic spectra that can be evolved over time. The system tends to either explode, reach timbral stability, or fall into silence. Global parameters that influence all delays, for example, can be controlled by hand movements. This control changes with each new set of connections. The instrument provokes a form of music making that is not comparable to playing traditional instruments; it is instead an artistic practice in the field of second-order musical cybernetics:[7] the instrument creates ever new sets that form nontrivial behaviour evolving over time. This behaviour is a result of the inner and outer complexity of the artefact. It can be observed and triggered by interaction in terms of movement. This serves to literally irritate the system as it becomes confronted with mechanical turbulence. According to the theory of second-order cybernetics (Foerster 2003), an observation process is not objective: artefact and observer, instrument and player are connected in a circular manner. The observer is a constitutive factor in the system. Taking this into account, she has to observe her process of observation or interaction. While this circularity may be seen as common in a design process, when applied to live performance, it may result in interesting shifts in common performance ecology (Bowers 2006): the performer cannot plan far into the future because she does not know how the instrument will behave. She can only anticipate future occurrences by actively listening to the instrument. In this sense, music making comes to be more about finding interesting correlations of movement and sound, instead of implementing such correlations beforehand.

## 6. CONCLUSION

In this paper, we presented the process of designing and building Push-Pull, a hybrid musical instrument prototype that uses the bellow as a physical interface. We described how complexity was implemented on all relevant levels in order to create a particular instrumental identity or gestalt. This required continuous decision-making, which we showed to be based on a set of considerations, associations, and convictions.

As outlined at the beginning, we argued that, in the case of electronic musical instruments, the dissolution of former causalities might bring about the establishment of new ones. Now that the once necessary union of sound generation and control in one device has become as optional as the correlations between material and sound and between playing action and resulting sound, it falls to the instrument maker to define instrument-specific causalities every step of the way. Once an instrument does not sound the way it does because it has a particular shape or is made from a particular material, the instrument maker has to decide why her instrument will sound like it does. Her justification will most probably not relate to physical aspects, but rather be underpinned by conceptual motivations. Rather than fixating on the length of strings or air columns when justifying the choice of a particular playing technique, the electronic instrument maker is most likely to simply be inspired by a specific gesture or a promising interface model, or could alternatively be a player already experienced in an existing technique. Similarly, the choice of a particular material only rarely re-

7. A good overview of second-order cybernetics by Ranulph Glanville can be found at *http://www.facstaff.bucknell.edu/jvt002/BrainMind/Readings/SecondOrderCybernetics.pdf*, 29 Oct 2014.

lates to its resonance quality; durability and aesthetic value are now more common concerns.

What can be observed here is a shift from physical necessities to aesthetic decisions. Instrument making is no longer a playful illustration of physical laws. Its process now resembles a decision tree. In this sense, we used the concept of complexity as a guiding principle through this tree, taking the idea of a coherent instrumental identity as our root.

While some new justifications develop out of the evolving instrument, others are grounded in individual choices. In both cases, they are a central part of instrument design and deserve much consideration.

Yet, there is one universal, recurring rationale that we became acquainted with during the process of designing and building PushPull. Sometimes, the best reason for a particular decision is simply: 'Because... I like it that way.'

## ACKNOWLEDGEMENTS

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