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The concept of excitation gesture in electronic instrument design

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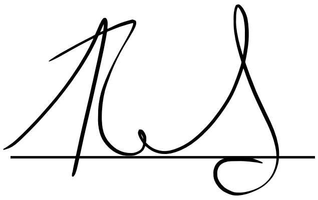

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Abstract

This thesis presents, explains, and discusses the three main categories of Claude Cadoz' Instrumental Gesture Typology. The applicability of the categories is examined on the basis of acoustical instrument case studies, with the conclusion that the limits of the framework are quickly reached during in-depth inspection due to ambiguity. However, for the purpose of using the typology as a reference point for the analysis of electronic instrumental interaction, the framework proves to be useful. Analysing the gestures performed on a range of electronic instruments shows that two of the categories, *modulation* and *selection*, are well established and refined, whereas the third, *excitation*, often shows need for further development both in terms of utilized sensor technology and complexity of interaction design. A number of promising electronic instruments are presented. Furthermore, the thesis suggests possible causes for the underdevelopment of *excitation* gesture, mentioning commonly used sensors, as well as trends in the commercial music industry. Ultimately, a range of concepts in electronic instrument design is presented and the benefits of including *excitation* gesture within these concepts are discussed. They include the notion of energy and effort, transparency of interaction, constraints, and audience perception.

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Introduction

Since the birth of electronic music, artists and researchers alike have been searching for ways to bring electronic music into a stage context. As a result, many performance practices have evolved, including loud speaker concerts (acousmatic), acoustical instruments and live electronics, purely electronic controller-based performances, and a multitude of hybrid forms.

The acousmatic tradition purposely takes the performer away from the spotlight, removing the performance element in order to fully focus on the sonic experience. Diffusion, the act of distributing an acousmatic piece over many speakers during concert, can be seen as performance. However, the diffusor is rarely the focus of the audience's attention and considered to be "performing" the music, but rather "adapting" the composition to the environment, which is the speaker system as well as the concert hall.

Any kind of performance involving acoustical instruments can utilize the possibilities of electronic sound production and manipulation, while also benefiting from a long and rich performance tradition of acoustical instrumental play, interpreting the music both auditory and visually. Audio processing of acoustical live input can be controlled by other performers, or through control parameters derived from the audio input, such as volume or pitch. The acoustical instruments can also be equipped with sensors to gather additional data. If this data (from sensors or derived from audio input) is used to control sound creation engines instead of audio processing of live input, the acoustical instrument's natural sound is no longer needed. In this case, the playing techniques can still be utilized to define the interaction between performer and instrument.

In controller-based performances without acoustical instruments it becomes more difficult to rely on the acoustic tradition to both guide performers and set audience expectations. This is especially true for electronic instruments, whose gestural repertoire does not resemble acoustic instrumental play. As electronic instrument designers create new ways of musical interaction, the electronic instruments are often unfamiliar to audience and performers. The design of instruments and their use in performance, while closely linked, each pose their own individual difficulties.

The design of electronic instruments for stage use is a young discipline compared to the long history of development in acoustical instrument making, instrumental play, and the resulting audience expectations. While electronic music has many possibilities and challenges unique to its field, there is still much common ground with the acoustical domain and electronic instrument designers can benefit from the latter's tradition in order to enrich contemporary electronic performance practice.

The core theme of this thesis is performer gesture, both in acoustical instrumental play and electronic performance. The main focus in the field of electronic instruments will lie on recently developed controller-based instruments that do not imitate existing acoustical ones. The first chapter presents the three main categories of Claude Cadoz' Instrumental Gesture Typology: *excitation, modulation*, and *selection*. The applicability of the typology will be determined on the basis of case studies with acoustical instruments. The typology is then applied to electronic performance practice, drawing parallels and identifying differences. Chapter 2 discusses possible reasons for the dominant roles of *modulation* and *selection* in electronic instrument design, identifying trends in sensor use and commercial industry demand. Chapter 3 subsequently presents the benefits of a design process with a stronger focus on *excitation* gestures, drawing from insights in the fields of electronic instrument design and psychology.

1 Cadoz' Instrumental Gesture Typology

In a publication from 1988 Claude Cadoz proposes an instrumental gesture typology as part of a compositional framework where "instrumental gesture is regarded as an object to be operated on by the composition" with the aim to "create concepts and pertinent tools for computer assisted musical creation."[1] He later revisits this

[1] Claude Cadoz, "Instrumental Gesture and Musical Composition," (presented at the International Conference on New Interfaces for Musical Expression, San Francisco, California, 1988), 1–12. p. 2

typology, defining sub-categories and providing case studies.[2] A discussion of the typology's sub-categories is beyond the scope of this thesis. The focus will lie on the three main classifications and how they can be applied in the electronic domain.

1.1 Definitions of Gesture

Definitions of the word gesture vary across disciplines. Outside the field of music, the word most often describes "a movement of the body, hands, arms, or head to express an idea or feeling."[3]

In order to include instrumental play, Cadoz extends this definition to physical manipulation, by regarding gesture as "all physical behaviour [...] by which a human being informs or transform his immediate environment."[4]

In the context of this thesis, I will focus on performer gesture, and, more specifically, 'effective' gesture as opposed to 'accompanying' gesture. 'Effective' gesture is defined as movement which is required for sound production, such as bowing or fingering. 'Accompanying' gestures like shifting the entire body, or changing the position of the instrument, are not required for instrumental play.[5] 'Effective' gesture is the element of performance that a designer can explicitly define, as he or she determines which movements are required for sound production and modification. 'Accompanying' gesture in turn is most often in the hands of the performer and thereby harder to influence from a design perspective.

1.2 Instrumental Gesture Typology

The three main categories of Cadoz' instrumental gesture typology are *excitation, modulation* (later renamed 'modification'), and *selection*. They will be illustrated using guitar performance as an example. In many cases these categories overlap in certain

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[2] Claude Cadoz and Marcelo M Wanderley, "Gesture-Music," *Trends in Gestural Control of Music*, 2000, 71–94.

[3] as defined in Paul Procter, ed., *Cambridge International Dictionary of English*, (Cambridge: Cambridge University Press, 2001).

[4] Cadoz, "Instrumental Gesture and Musical Composition." p. 5

[5] Francois Delalande, "Le Geste, Outil D'Analyse: Quelques Enseignements D'Une Recherche Sur La Gestique De Glenn Gould," *Analyse Musicale: Geste Et Musique* 10 (1988): 43–46.

areas. Significance and applicability of the typology is evaluated in chapter 1.3. All three gesture types can be seen as 'effective' gesture, as they all play a role in the sonic outcome.

Excitation is the process of sending energy into a vibrating structure. It is required for the resulting sound phenomena, as it generates the vibrations which are shaped and guided by *modulation* and *selection*. Plucking a single string can be seen as an *excitation* gesture, as can strumming all strings, hitting the resonating body, and audibly sliding fingers along the strings. To determine if a gesture is in fact an *excitation* gesture one can look at the energy contour of a sound during and after movement. If a sound decays once the gesture is no longer performed, it was caused by an *excitation* gesture.

Modulation gestures shape vibration patterns by changing a resonator's characteristics. "There is no, or very little energy used up, and in any case, this energy plays no part in vibration."[6] Left hand vibrato and using the tremolo arm of an electric guitar can be classified as *modulation* gestures influencing pitch. Fingering along one single string can be seen as a *modulation* gesture modifying string length.

Selection gesture is defined as a "choice among multiple similar elements in an instrument,"[7] neither providing energy to the vibrating structure nor changing its properties. Choosing which string to perform fingering on with the left hand can be categorised as a *selection* gesture, as can lifting a string with the right hand prior to releasing it.

1.3 Gestures performed on a selection of acoustical instruments

The gestures performed on the following acoustical instruments will be analysed by strictly applying the categories proposed by Cadoz. Possible ambiguity in

[6] Cadoz, “Instrumental Gesture and Musical Composition.” p. 7
[7] Cadoz and Wanderley, “Gesture-Music.” p. 80

categorization or limitations of the typology will be addressed at the end of the chapter.

When examining the instrumental gestures performed by a cellist, one can see the left hand as performing *selection* when placed on one of the four strings, and *modulation* when playing fixed notes or glissandi on said string (thereby modifying the length of the string). The right hand provides *excitation* and creates volume and timbre contours. Bowing parameters such as pressure and speed are a decisive factor in the resulting sound, shaping dynamics and articulation. Flageolet fingering is a *selection / modulation* gesture that also has a strong impact on the resulting timbre. Left-hand pizzicato, and percussive fingerings are *excitation* gestures.

The piano has a strong focus on *selection* and *excitation* gestures. The former chooses the key to be pressed, while the latter determines the force with which the key is pressed. The expressivity of play is greatly influenced by distinct differences in attack. As long as the player does not perform actions inside the piano, *modulation* of a sounding event is limited to the use of the pedals, whose control is mainly non-continuous.
If extended playing techniques and preparation of the instrument is included, *modulation* becomes more common, as the possibilities of damping strings become more diverse and continuous. Additionally, *selection* gestures now expand from key choice to adding and removing additional resonating elements from inside the piano.

In the case of the trombone, pitch control is done via *selection* and *modulation* gestures, just as with the cello. As the length of the trombone tube is one continuous parameter, the lines between the two above-mentioned gesture types are blurry. One could consider the change of lip tension to produce a different overtone a *selection* gesture, and the right hand pitch control a *modulation* gesture. *Excitation* is provided by breath pressure, shaping dynamics and temporal contours. The use of mutes provides the left hand with additional *modulation* possibilities.

Just as piano performance, drumming is mainly determined by *selection* and *excitation*. In the case of the drum set, *modulation* almost does not occur. Positioning the drum stick in front of the desired drum is *selection*, as is the chosen impact

position on the drum. Hitting the felt is excitation. In expert instrumental performance, *selection* gestures are performed fast and precisely, and *excitation* gestures have diverse and distinguished attacks.
Running a drum stick along a cymbal represents a non-percussive *excitation* gesture. Damping a cymbal with the hand after hitting it is a *modulation* gesture. In the extended family of percussion instruments *modulation* and non-percussive *excitation* become more common.

When examining these case studies, *excitation* emerges as an essential aspect of instrumental performance, and as a defining factor in expressive and musical play. Nuances in this type of gesture are in many cases what differentiates a student or amateur instrumentalist from an expert.

Looking at the categorisations above and at Cadoz' own example classifications, it becomes clear that many instrumental gestures can either be assigned to several gesture types or can be divided into countless sub-categories. For example, in the case of the clarinet, he defines changes in lip pressure as *modulation*, while the closely related breath pressure is *excitation*. However, he does not do this in the case of bowing, where a similar sub-categorization would be possible (bowing intensity, and pressure applied to the bow). This shows that at a certain depth of analysis, the lines between the categories become blurry, ambiguous and open to interpretation. Forcing all the different forms of instrumental play into a firm categorization is not particularly beneficial. However, using general terms to describe different aspects of instrumental performance can provide a frame for comparison with electronic instrumental play, which is what the categorisation is used for in the context of this thesis. As Cadoz states, the purpose of the gesture typology is "not to completely describe acoustic musical instruments but to provide general guidelines for the design of gestural input devices."[8]

[8] ibid. p. 82

1.4 Gestures performed on a selection of electronic instruments

The following (by no means exhaustive) list of electronic instruments has been chosen based on its capability to represent varying types of interaction, and availability of documentation in form of both publications, and video recordings of performances. This allows clearly determining the aims and methods of the designers as well as evaluating their success. The instrument interaction is described using only the vocabulary of Cadoz' typology.

The Music Production Center ("MPC") is a pad-based controller firmly established in the electronic music industry since its first model was released in 1988 by the Japanese company Akai. It provides 16 pressure-sensing pads which are mapped to samples determined by the user. The pads are velocity-sensitive, allowing the player to control starting point and volume. Classifying the instrumental gestures performed on the device show similarities to the piano: choosing which sound to trigger is *selection*, while the velocity with which the pad is hit equates to *excitation*. Without modifying the standard behaviour of the mappings, and without additional knobs on the device, *modulation* gestures are not possible.
This setup is similar for many keyboards and pad-based controllers that are commercially available.[9] The precision of velocity sensing is constrained by hardware limitations as well as the resolution of transmission protocols (MIDI). As a result, most keyboards and pad-based controllers allow piano-oriented interaction with reduced subtlety in control. The keyboard-specific controls pitch-bend and the modulation wheel are commonly used to perform *modulation* gestures.

The Quarterstaff, designed by Jan Schacher at the ZHdK Zurich, is a gestural sensor instrument resembling a medieval fighting stick. The arm-long device contains a range of motion sensors, providing accelerometer, gyroscope, and compass data. Further sensors include pressure sensing pads, and a potentiometer, which is located at a rotatable joint at the centre of the instrument.[10] In performances[11] with

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[9] Excluding the ones with 'aftertouch' functionality. These provide an additional control parameter through sensing pressure after the key was initially hit.
[10] J C Schacher, "The Quarterstaff, a Gestural Sensor Instrument.," (presented at the International Conference on New Interfaces for Musical Expression, Daejeon, Korea, 2013), 535–40.

the instrument, the most apparent instrument interaction is the control of pitch-related parameters through changes in the devices orientation. Moving the device influences sonic events, while holding it still results either in static tones or tones with a fixed modulation rate. With the energy input of the performer playing no visible part in the creation of the sound, but volume and timbre being determined by the orientation of the device, this type of control can be seen as *modulation* gestures. The pressure-sensitive pads and the potentiometer allow additional *modulation* and *selection*. At certain points[12] in the performance, sudden gestures result in more percussive elements being triggered. These gestures link a sonic event to the energy input of the performer and can therefore be classified as *excitation* gestures. In an article on the design of the instrument, the author states that "[a] stroke that is recognised through an acceleration peak located within a specific quadrant can be mapped to one thing, while the same stroke in a different direction will mean something else."[13] Choosing which direction (gathered from compass data) to do the stroke in would be a *selection* gesture. The overall gesture fuses these two gesture types. It is unclear, whether the amount of energy going into a stroke is a parameter used in the sound creation, but at least from an audience perspective velocity control is not detectable.

The Mimu Gloves were developed in a collaborative effort of researchers and artists, the latter's most prominent member being singer and songwriter Imogen Heap. The instrument consists of two gloves equipped with motion and bending sensors. Machine learning techniques were used to detect hand postures from data provided by the bending sensors on each finger.[14] Accelerometer data is mostly used for hand orientation measurements, allowing mapping of parameters to turning of the hands or lifting the arm. A common use of the interface is to control processing on live audio such as voice input. Control parameters such as amount of reverberation are *selected* through hand postures and then *modulated* through hand orientation or, at

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[11] A performance of the piece "The possibility of an Island, Part 2: Elements" realised using the Quarterstaff can be seen at https://vimeo.com/66888735 (date of access: 03.05.2016)
[12] For example, at 4:56 of the above-mentioned performance recording https://vimeo.com/66888735 (date of access: 03.05.2016)
[13] ibid. p. 538
[14] T J Mitchell, "Soundgrasp: a Gestural Interface for the Performance of Live Music," (presented at the International Conference on New Interfaces for Musical Expression, Oslo, Norway, 2011), 465–68.

times, player position on stage.[15] *Excitation* gestures are used in some mappings for the instrument. These are elaborated on in chapter 1.5.

The Sponge is a digital musical instrument (DMI) developed by Martin Marier at the University of Montréal. As the name suggests, it consists of a small selection of sensors wrapped in foam. The sensors used are two accelerometers and two force-sensing resistors, allowing the interface to sense motion and orientation, as well as pressure at certain points of the interface. Later, undocumented versions of the instrument include buttons. The motivation behind the design was to establish "a clear link [...] between gesture and sound."[16] In the instrument's performances[17] this is demonstrated convincingly. Micro movements of fingers and hands clearly correspond to granular sound fragments. Slow, soft finger tapping is sonically clearly distinguishable from energetic and fast impacts. In the context of the instrument, these gestures can be seen as *excitation* gestures. Using buttons to change the behaviour of the instrument can be interpreted as a *selection* gesture. Changing the timbre through tilting, rotating, or squeezing the device would then be *modulation*.

These case studies suggest that electronic instrument design has a bias towards *selection* and *modulation* gestures. The concept of *excitation*, while often present, only makes up a small part of overall instrument interaction, and is in many cases underdeveloped. It does not provide as many interaction possibilities and refined control as the other two gesture types. In electronic instruments that focus on audio processing of live input, such as many mappings of the Mimu gloves, the above-mentioned bias is understandable, as the sound creation (including *excitation*) is done by acoustical sources and the interface is merely an extension of the overall instrument. Once sound creation plays a more prominent role in the electronic instrument interaction, *excitation* begins to play a bigger role as well. The following chapter will examine a range of electronic instruments that place more focus on this type of gesture.

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[15] An example of the Mimu Gloves control over processing of live audio input can be seen at https://www.youtube.com/watch?v=LoUOmNO9tTA and https://www.youtube.com/watch?v=YwYE_Up8K4s (date of access: 03.05.2016)
[16] Martin Marier, "The Sponge: a Flexible Interface," (presented at the International Conference on New Interfaces for Musical Expression, Sydney, Australia, 2010), 356–59. p. 356
[17] A demonstration of The Sponge can be seen at https://vimeo.com/118436006 (date of access: 03.05.2016)

1.5 Focusing on excitation gesture

A mapping of the Mimu Gloves approximating harp playing[18] does require the player to perform movement in order to cause (virtual) vibration and produce a sonic result. It can therefore be seen as an *excitation* gesture. However, movement intensity and speed have no influence on timbre or any other sonic parameters. Sounds are *selected* and triggered through hand postures. The arpeggios correspond to longer gestures of the arm and hand, but their progression is determined at the point of triggering and cannot be influenced afterwards. It therefore appears like a continuous *excitation* gesture, as there is a visual link between gesture and sound, when in fact the control over the sound does not extend the initial triggering.
A different mapping allowing the triggering of drum samples through percussive mid-air gestures[19] is using *excitation* gestures to determine the moment a sound gets triggered. Velocity control, and thereby timbre control, is again not implemented. *Selection* of drum sounds is achieved through different hand postures. This can be seen as an equivalent to the sound selection through quadrant detection in the Quarterstaff mappings (see 1.4).

The Pointing-at Glove is the result of a PhD project by Guiseppe Torre at the University of Limerick. The instrument interaction was designed around "gestural performative actions which are both visually and sonically legible to audience members and that retain a high level of controllability ('control intimacy') from the performer perspective."[20] Besides the common pursuit of high-quality interaction between performer and instrument Torre also aimed at maximising "understanding from an audience perspective."[21]
'Agorá', a piece performed with the Pointing-at Glove,[22] shows an unusual dominance of *excitation* gesture. The interaction with the instrument almost exclusively consists of bowing-like gestures, controlling volume curves of sonic

[18] The mapping can be seen at https://www.youtube.com/watch?v=Bp0d7-86eaI (date of access: 03.05.2016)
[19] This mapping is demonstrated at https://www.youtube.com/watch?v=Gp7--niwwOI (date of access: 03.05.2016)
[20] Giuseppe Torre, "The Design of a New Musical Glove: a Live Performance Approach," (University of Limerick, 2013). p. 165
[21] ibid. p. 27
[22] A performance of the piece can be seen at https://vimeo.com/44650248 (date of access: 03.05.2016)

textures, characterised by slowly building attack phases and reverberant resonances. The spatial distribution of sound in the quadraphonic piece is determined by the orientation of the performer's hand. He is 'pointing-at' the location of the sound source. In this case, *excitation* (sound creation) and *modulation* (localization) are fused into one gesture, just like in countless gestures from acoustic instrumental play. Through the loss of high frequency content in the reverb tails, the *excitation* gestures are in some way linked to the timbre of the sounds, as a decrease in movement energy corresponds to the decay of a sonic event.

The Twister is a more recent design of Torre in collaboration with Nicolas Ward. Its characteristics are developed out of an "explicit consideration of the type of movement [the designers] would like the device to engender in performance."[23] The device consists of two cylindrical discs, whose distance and rotation in respect to each other is measured through an optical encoder and a short-range infra-red sensor. A motion sensor is included as well. The interaction with the Twister is dominated by shaking, pulling apart and pushing together, and turning gestures.[24] As intended by the designers, the interaction approximates that of an accordion player. All three control movements give the impression of being *excitation* gestures, as they are visually coherent with the metaphor of sending energy into a vibrating structure. This corresponds well to the designers' description of a 'movement-based design process'. If we take a closer look at some of the mappings of the instrument, we find that the absolute distance between the discs is used to determine the volume of a sound. Therefore, the act of moving the discs closer or further apart from each other can be classified as a *modulation* gesture. In this case the interaction differs from that of the accordion player, who is required to provide constant movement energy in order to keep the air flowing and his instrument sounding.

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[23] Nicolas Ward and Guiseppe Torre, “Constraining Movement as a Basis for DMI Design and Performance,” (presented at the International Conference on New Interfaces for Musical Expression, London, United Kingdom, 2014), 449–54. p. 449

[24] The Twister and all mentioned interaction types are demonstrated at https://vimeo.com/75591098 (date of access: 03.05.2016)

The Gesture-based Performance System is an electronic instrument designed by the author in collaboration with Cedric Spindler.[25] The core design principle is a dominant use of *excitation* gesture in the interaction with the instrument. The two main gesture metaphors are 'striking' and 'bowing'.[26]

'Striking' is a percussive gesture focusing on *excitation*. Trigger gestures are detected and so is the performer's movement energy at the point of triggering. This allows timbre / velocity control. The sound material for this interaction type consists or pre-recorded impacts of varying intensity. The sounds get chosen according to the energy content of the trigger gesture. This selection of the sound material is therefore closely linked to the *excitation* gesture. *Selection* gestures themselves are not implemented in this case.

'Bowing' is a continuous *excitation* gesture. As in the bowing of instrumental play, perceived timbre corresponds to the gesture's energy content. This type of interaction contains no elements of *selection*, as there are no equivalents to a string player's possibility to change string or fingering.

In the cases presented above, the concept of *excitation* gesture dominates the interaction with the instruments. In many cases this leads to a reduced number of controllable parameters, as the *excitation* replaces its two more versatile counterparts. For example, in the case of the Twister, data from the built-in 3d accelerometer is pooled and turned into one 'shaking' parameter, instead of 3 different *modulation* gesture parameters.

In comparison to acoustical instruments, *excitation* gestures in these cases seem to be underdeveloped. In many cases, percussive triggering does not have velocity control, and continuous control rarely influences more than volume. Control subtlety and mapping complexity are poor compared to acoustical instruments, and also compared to the more refined *modulation* and *selection* gestures in electronic instruments. It seems that *excitation* has been receiving comparatively less attention

[25] Frederic Robinson et al., "Gestural Control in Electronic Music Performance: Sound Design Based on the 'Striking' and 'Bowing' Movement Metaphors," (presented at the Audio Mostly Conference on Interaction With Sound, Thessaloniki, Greece, 2015), 26:1–26:6.

[26] A demonstration of both gesture metaphors can be seen at https://vimeo.com/134536867 (date of access: 03.05.2016)

in the history of electronic instrument design, especially with instruments, that do not draw inspiration from acoustical instruments, also known as 'alternate controllers'.[27]

2 Trends towards modulation and selection

Working under the assumption, that *excitation* has so far received less focus and development efforts than *modulation* and *selection*, the question comes to mind, how this bias originated. The following chapter will attempt to answer this question by describing general trends in sensor use in electronic instrument design, as well as commercial industry demands, explaining how they do not encourage the implementation of *excitation* gesture.

2.1 General trends in sensor use

The community around the annual conference on New Interfaces for Musical Expression (NIME) is currently the main contributor of novel electronic instruments. In an extensive review by Medeiros and Wanderley, information on sensor use was gathered from 266 instruments that emerged from research within the NIME community.[28] Examining the most commonly used sensor technology in electronic instrument design, namely potentiometers (knobs and faders) and buttons, infra-red sensors, inertial measurement units (accelerometers and gyroscopes), and force-sensing resistors, we see a selection of specific types of data, that these sensors standardly provide. From this we can then assume their most obvious use in subsequent control mappings.

Potentiometers commonly supply absolute position values. These change when the knob or fader is being turned and steadily remain on their new value once the potentiometer is released. This lends itself well to all kinds of *modulation* as well as *selection* as the knob or fader is being turned with the goal of reaching a specific new

[27] Marcelo M Wanderley, "Gestural Control of Music," (presented at the International Workshop Human Supervision and Control in Engineering and Music, Kassel, Deutschland, 2001), 632–44.
[28] Carolina Medeiros and Marcelo Wanderley, "A Comprehensive Review of Sensors and Instrumentation Methods in Devices for Musical Expression," *Sensors* 14, no. 8 (2014): 556–91.

value or state, and remaining at that value. Buttons which are not velocity sensitive commonly have two states: 'on' and 'off'. Depending on how their data is treated they turn 'on' once pressed and 'off' after another button press. In other cases, the 'off' message comes directly at the release of the button. They are commonly used in higher numbers and usually provide *selection* possibilities. Buttons are often added to an electronic instrument to provide simple and unobtrusive functionality to control more global parameters. The Twister (see 1.5) and the Sponge (see 1.4) both make use of this.

Infra-red Sensors measure the absolute distance to a surface or object, for example between the two discs of the Twister. As with potentiometers, this makes them useful for use with *modulation* gestures. This is also the case for more advanced visual sensor techniques such as video tracking, where the first step of analysis often results in absolute x/y position values. Adding the measuring of depth increases the amount of possible control parameters but not the type of gestures associated with them: *modulation* and *selection*.

Inertial measurement units (accelerometers and gyroscopes) commonly provide data on their orientation in three-dimensional space as well as the speed of their angular rotation. Even though the orientation data is provided in form of acceleration values, the constant gravitational influence of the earth turns it into absolute orientation values, that are most reliable when the device is not being moved. As a result, the acceleration data is frequently used in conjunction with *modulation* or *selection* gestures, as, for example, in the case of the Quarterstaff (pitch and frequency modulation control), many of the Mimu Glove mappings (repetition speed of loops or amount of reverberation), and the Twister (chord *selection* through segmented tilting of the device). Angular rotation speed is the only type of sensor data in this list which cannot be used for *modulation* or *selection* gestures without additional data interpretation. Its values are only meaningful during movement which makes it a natural candidate for the use with *excitation* gestures.

Force-sensing resistors can be used to measure pressure. This adds an additional layer of information to simple 'on' / 'off' states. Since pressure is a parameter closely linked to a performer's applied force, one could assume it to be a natural candidate for *excitation* gestures. However, apart from very few exceptions such as the bagpipe or the accordion, pressure does not set acoustical instruments into vibration if it is not combined with additional movement into a direction which is different from the direction of the pressure. It can rather be seen as an additional characteristic of movement-dominated *excitation* gestures. Pressure on a bow, for example, will greatly influence timbre of the resulting sounds, but only as long as the bow is also being moved on the horizontal axis. In the case of woodwind instruments breath pressure does provide the *excitation*, but the closely-related lip pressure (where relevant) does not. In Cadoz' typology**,** he even goes as far as to categorise lip pressure separately as *modulation* gesture (see the ambiguities of the typology mentioned in 1.3). In conclusion, the gesture of applying pressure is either an element of *excitation*, which can not provide *excitation* on its own, or a *modulation* gesture. This means, that without sufficient abstraction, pressure sensors are not immediately usable for the detection of *excitation* gestures.

It is important to note, that the above-mentioned data types are only the standard output format in most sensor technology systems. Through the use of data interpretation techniques, all of these sensors can be made suitable for any of the gesture types. Integrated angular rotation speed provides absolute values, that can be used to replace the functionality of a potentiometer. Computing the derivative of data from a fader will result in information about the speed of the movement performed. This data can then be used as a representation of the movement speed of a bow. The fact that gathering these types of information requires additional layers of abstraction, does not make it impossible to use sensors for non-standard mapping applications. However, it makes it more unlikely.

2.2 Commercial music industry demands

Looking at the commercial music industry, it becomes clear that *modulation* and *selection* are dominating the market much more than in projects coming out of the academic environment. Potentiometers and buttons are the most commonly used sensors. As the industry is oriented towards customer demand, there have to be characteristics of *excitation* gesture and the sensors associated with it, that make them undesirable or uninteresting for the consumers.

The target audience for industry controllers tends to be producers of electronic music as opposed to practicing performers. Their focus often lies on composition, sound design, and how to bring their studio work to the stage. Instrumental performance is rarely a priority. As a result, controllers are meant to provide control over parameters that deal with the *management* of sonic material in an abstracted way, rather than parameters directly connected to sound creation. For example, in commercial electronic music performance it is more common to control the audio processing of a drum track than to trigger the individual drum sounds. It is more common to modify the amount of reverberation on a pre-recorded polyphonic synthesizer pattern than attempting to reproduce the individual voices. Some of this *management* concept might have come out of the DJ tradition, where the electronic performer exclusively works with complete pieces of music, having his control mostly limited to the choice of music, and the pacing of the transitions.
Modulation and *selection* gestures work well with abstract, global, *management*-related parameters, while *excitation* is most fit for direct control over sound creation.

In order to become and stay relevant on the market, control devices need to be as compatible as possible to allow customers an easy integration into their individual setups, as well as long-term use in conjunction with the common synthesis methods. One particular result of this need for compatibility is the lasting relevance of the MIDI protocol, which continues to be the dominating form of communication between devices in the electronic music industry, such as controllers and analogue synthesisers. In the meanwhile, academic and non consumer-oriented projects have long switched to more advanced protocols with higher resolutions such as Open Sound Control (OSC).[29] The requirement of compatibility makes it difficult for new forms of instrumental interaction to establish themselves, as it would be necessary for all modules of the often fragmented electronic setups to adapt at the same time. Since we are talking about instruments, there is also a certain amount of emotional

[29] M Wright and A Freed, "Open Sound Control: a New Protocol for Communicating with Sound Synthesizers," (presented at the International Computer Music Conference, San Francisco, USA, 1997), 10–22.

attachment involved, that makes consumers less likely to welcome new methods of control, if they are incompatible with what they currently own. Analogue synthesisers are much harder to let go of or replace than printers.

3 Excitation in the context of electronic instrument design

In the large body of research concerned with electronic instrumental performance a range of concepts has emerged that are said to enrich performance experiences for performers and audiences alike. The following chapter will highlight some of the concepts and show how they can benefit from the use of *excitation* gesture.

3.1 Energy and effort

Various publications have linked expressive musical interfaces to the concept of expended 'energy' and 'effort'.[30][31]

> *"The richness of physical control required for performance with traditional acoustic musical instruments takes time to learn. In many computer interfaces this is often replaced by sets of choices that the user must continuously think about."*[32]

In this context it appears reasonable to link the term 'physical control' to *excitation* and 'choice' to *selection*.

In a study performed by Andy Hunt and Ross Kirk, different mapping strategies using the same input devices where tested for their potential of letting the user improve over time (a key characteristic of acoustical instruments) and for their ability to enable the execution of 'complex musical tasks' (a 'laboratory' version of musical performance).[33] One of the testing setups included the use of *excitation* gesture in

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[30] Joel Ryan, "Some Remarks on Musical Instrument Design at STEIM," *Contemporary Music Review* 6, no. 1 (1991): 3–17. p. 7
[31] Atau Tanaka, "Musical Performance Practice on Sensor-Based Instruments," *Trends in Gestural Control of Music*, 2000, 389–405. p. 401
[32] Andy Hunt and Ross Kirk, "Mapping Strategies for Musical Performance," *Trends in Gestural Control of Music*, 2000, 231–58. p. 231
[33] ibid.

order to create sound. This was done by mapping the movement speed of a regular computer mouse to the volume of the sound engine, expecting the user "to expend some physical *energy* to continuously activate the system."[34] The results of the study suggested, that the above-mentioned mapping was most successful in its potential for improvement and the solving of complex musical tasks. Besides utilizing *excitation* gesture the mapping also pooled control parameters in what Rovan et al. call a 'convergent' mapping,[35] using several movement features to control one sonic feature. Hunt and Kirk further describe said mapping as the 'most musically expressive from an instrumental point of view, although not always immediately obvious to implement."[36] The success of the energy-dependent instrument design by Hunt and Kirk can be traced back to its use of *excitation* gesture and a 'convergent' mapping strategy.

In this context, an anecdote from another publication Hunt co-authored[37] seems worthy of mention. When examining a range of student projects he came across a Theremin implementation done with modern electronic circuitry. A "wiring mistake by the student [led to] the 'volume' antenna only [working] when [the performer's] hand was moving,"[38] thereby turning the volume-controlling *modulation* gesture of the original Theremin into an *excitation* gesture. According to Hunt et al., the interaction "felt as if your own energy was directly responsible for the sound," allowing the "subtleties of the bowing movement [to give] a complex texture to the amplitude."[39]

3.2 Transparency and metaphors

Another term often mentioned in connection with instrument design is 'transparency'. In this case, it describes the understanding of the performer in regards to his instrument, with the focus being on intuitive understanding, rather than 'learning by

[34] ibid. p. 238
[35] Joseph Rovan et al., "Instrumental Gestural Mapping Strategies as Expressivity Determinants in Computer Music Performance," (presented at the Kansei - The Technology of Emotion Workshop, Genoa, Italy, 1997), 3–9.
[36] ibid. p. 5
[37] Andy Hunt, Marcelo M Wanderley, and Matthew Paradis, "The Importance of Parameter Mapping in Electronic Instrument Design," *Journal of New Music Research* 32, no. 4 (2003): 429–40.
[38] ibid. p. 429
[39] ibid.

heart.' Fels et al. see a direct connection between the transparency of an instrument, and its expressivity, stating that the instruments that are most transparent to both performer and audience are also the most expressive.[40] This statement has to be viewed critically, as it omits the concept of performer skill, and expressive instrumental play surely must require skilful performers. However, transparency and intuitiveness certainly play an important role in instrument design. According to Fels et al., "full transparency for the player means that the device's output exactly matches the player's expectation and control."[41] Matching the players expectation with a sonic result is a task quite fitting for *excitation* gestures. Humans' innate understanding of physical processes around them makes the action-reaction patterns of *excitation* natural and intuitive. Even in acoustical instruments, the cause-effect mechanisms of *modulation* and *selection* gestures are usually less transparent and intuitive than *excitation* gestures, as for example in trumpet fingering. Therefore, if the aim is to create more transparent musical interfaces, *excitation* gesture is a valuable tool.

Design approaches focusing on transparency and intuitiveness often make use of control metaphors. These are performer gestures based on commonly known actions or broader concepts whose knowledge or experience is shared by performer and audience. By using metaphors, instruments do not need to explicitly 'explain' their interaction, because the 'rules' are already known. This is naturally the case in acoustic instrumental performance.
According to Fels et al., "the application of a metaphor to an interface has the effect of increasing its transparency for both the player and the audience."[42] Fels himself has been involved in a range of electronic instruments which use metaphors to provide intuitive interaction. These metaphors include the gestures associated to sculpting clay,[43] playing the guitar,[44] and imitating lip movement with the hands.[45]

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[40] Sidney Fels, Ashley Gadd, and Axel Mulder, "Mapping Transparency Through Metaphor: Towards More Expressive Musical Instruments," *Organised Sound* 7, no. 2 (August 2002): 109–26.
[41] ibid. p. 110
[42] ibid. p. 120
[43] Axel Mulder, Sidney Fels, and Kenji Mase, "Design of Virtual 3D Instruments for Musical Interaction," *Graphics Interface* 99 (1999): 76–83.
[44] Sidney Fels and Kenji Mase, "Iamascope: a Graphical Musical Instrument," *Computers & Graphics* 23, no. 2 (1999): 277–86.

Wessel et al. suggest the use of drag & drop, and scrubbing among others.[46] Both of these are quite common in modern-day interaction especially with smart phone touch screens. Lewis and Pestova propose a slightly different vocabulary, not specifically for the use in instrument design, but for electronic music in general. In their gestural typology for mixed electronic music, they define 'sounding gesture' as the "sonic manifestation of any human physical action"[47] By this they combine physical movement by the performer and sonically perceived gestures into one term. Their repertoire of gesture descriptions includes bowing, scraping, pushing, striking, and agitating.[48]

All these metaphors use a common understanding of their underlying concept to increase the transparency of the instrument interaction that they are used in. Most of them specifically represent physical actions such as forming something through the use of pressure (sculpting clay), dragging something across a surface (drag & drop, scraping) or continuously striking something to cause and sustain resonance (agitating). Once physical forces are involved, *excitation* becomes a core aspect, and can be helpful in convincingly implementing the above-mentioned gesture metaphors.

3.3 Constraints

Another aspect of electronic instrument design is the concept of constraints. These are said to be an important part of the development of creativity, if not even a prerequisite.[49] In the more specific context of electronic instrument design, constraints have shown to encourage creativity in the interaction with technology.[50]

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[45] Sidney Fels and Geoffrey Hinton, “Glove-TalkII - a Neural-Network Interface Which Maps Gestures to Parallel Formant Speech Synthesizer Controls,” *IEEE Transactions on Neural Networks* 9, no. 1 (1998): 205–12.
[46] David Wessel and Matthew Wright, “Problems and Prospects for Intimate Musical Control of Computers,” *Computer Music Journal* 26, no. 3 (2002): 11–22.
[47] Andrew Lewis and Xenia Pestova, “The Audible and the Physical: a Gestural Typology for Mixed Electronic Music,” (presented at the Electroacoustic Music Studies Network Conference, Stockholm, Sweden, 2012), 1–13. p. 2
[48] 'Bowing' and 'Striking' are the two core gesture metaphors in the Gesture-based Performance System (see 1.5)
[49] Margaret A Boden, *The Creative Mind*, (London: Psychology Press, 2004). p. 95
[50] Victor Zappi, “Design and Use of a Hackable Digital Instrument,” (presented at the International Conference on Live Interfaces, Lisbon, Portugal, 2014).

Thor Magnusson suggests the design of constraints as a countermeasure against a possible "creative paralysis" resulting from the "practically infinite expressive scope" of electronic sound creation.[51] Having a limited range and expression focuses the interaction with the instrument and possibly provides a clear range of performance gestures, which are easy to get acquainted with, when the performer is not yet familiar with the instrument. Constraints can be implemented in a multitude of ways, from designing the instrument with a clear picture of possible movements in mind[52][53][54] to enabling performers to modify the functionality of their instrument.[55] Additionally, "composers and performers must also engage with the physical constraints of the musical instrument that they are composing for or playing."[56] Physical constraints can be by built into an electronic instrument through hardware design by, for example, placing input controls at certain positions on the instrument. They can also be implemented using physical limitations of the performer, such as reach, strength, or movement speed. Haptic feedback mechanisms in instruments with force-feedback joysticks have been used to constrain performer movement.[57][58] As in many other aspects of electronic instrument design that involve physical performer movement, the concept of *excitation* gesture can here be applied as well. Any kind of *excitation* implies physical effort by the performer and with effort come constraints, a natural development of a players physical capabilities. A quite radical implementation of this is the piece "Hypo Chrysos" by Marco Donnarumma,[59] in which bio signal data of muscle tension is used to create and process dense

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[51] Thor Magnusson, “Designing Constraints: Composing and Performing with Digital Musical Systems,” *Computer Music Journal* 34, no. 4 (2010): 62–73. p. 62

[52] Ward and Torre, “Constraining Movement as a Basis for DMI Design and Performance.”

[53] Mads Jensen, Jacob Buur, and Tom Djajadiningrat, “Designing the User Actions in Tangible Interaction,” (presented at the Conference on Critical computing: between sense and sensibility, New York, USA, 2005), 9–18.

[54] In that case one could also speak of 'affordances', emphasizing which movements are 'encouraged' rather than 'prevented'.

[55] Zappi, “Design and Use of a Hackable Digital Instrument.”

[56] Magnusson, “Designing Constraints: Composing and Performing with Digital Musical Systems.” p. 63

[57] David Howard, Stuart Rimell, and Andy Hunt, “Force Feedback Gesture Controlled Physical Modelling Synthesis,” (presented at the Conference on New Interfaces for Musical Expression, Singapore, 2003).

[58] Hans-Christoph Steiner, “StickMusic: Using Haptic Feedback with a Phase Vocoder,” (presented at the Conference on New Interfaces for Musical Expression, Hamamatsu, Japan, 2004).

[59] A performance of "Hypo Chrysos" can be found at https://vimeo.com/37921373 (date of access: 03.05.2016)

soundscapes.[60] Over the course of the piece, the performer uses ropes to pull two 25kg concrete blocks on stage, steadily approaching his physical limits. The sonic material of the piece is live audio input: vibrations caused by the performers muscle activity. Therefore, the performer movement can in some way be seen as *excitation* gesture. However, the sensor sensitivity is so high, that the system "captures *any* sonic event from within [the] body,"[61] blurring the distinction between 'effective' and 'accompanying' gesture (see 1.1).

3.4 Audience perception

A recurring theme in electronic instrument design is the pursuit of a clear and coherent audio-visual link.

> "[...] *Clarity of the cause/effect mechanisms are sought for the benefit of both the performer and the audience. Gestures* [...] *represent a visual stimuli that, when coupled with the current auditory scene, can give an insight into the instrument's controls, mapping techniques and the performer's virtuosity."*[62]

This leads to the question, what role audience perception should play in electronic instrument design. According to Fyans et al., instrument designers tend to "treat musical expression as an extra-musical quantity contained within a work or performance, with little regard to the audience's role."[63] It appears reasonable to limit the pursuit of expressive musical instruments to performer, instrument, and music, especially is the aim is authentic instrumental play as opposed to sensationalism through exaggerated 'showmanship'. However, ignoring the role of the audience does not automatically lead to more authentic instruments and since many of the

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[60] Marco Donnarumma, "Performing Proprioception and Effort in 'Hypo Chrysos', an Action Art Piece for the Xth Sense," *Econtact.Ca*, accessed May 2, 2016, http://www.econtact.ca/14_2/donnarumma_hypochrysos.html.
[61] ibid.
[62] Torre, "The Design of a New Musical Glove: a Live Performance Approach." p. 24
[63] A Cavan Fyans, Michael Gurevich, and Paul Stapleton, "Where Did It All Go Wrong? a Model of Error From the Spectator's Perspective," (presented at the International Conference on New Interfaces for Musical Expression, Pittsburgh, USA, 2009), 171–72. p. 171

concepts mentioned in this chapter are beneficial for both performers and audience,[64] involving the latter does not have a negative influence on the other aspects of the design process.

Various studies[65] have suggested that visual stimuli influence our perception of sound. Morrison et al. show that the expressivity of conductor gestures influences an audience's overall evaluation of performance expressivity, and more specifically, the perceived quality of articulation and dynamics.[66] An article by Vines et al. shows that this is the case in instrumental performance as well. Here, participants were asked to specify the perceived 'tension' of solo clarinet performance.[67] Thompson et al. link performers' facial expressions to perceived emotional content. In a study they filmed performers singing major and minor thirds, and subsequently had participants specify how 'sad' or how 'happy' they perceived the interval to be. Through swapping the audio track of the recordings, they tested visual and sonic cues independently. Results included major thirds being perceived as 'less happy' when they were played in combination with a video recording of a performer singing a minor third.[68] This means that a performer's less intentional visual cues (such as facial expression while singing a major or minor third) influence audience perception as well as more intentional ones (such as conducting more or less expressively). Another study shows that performer gestures by percussionists influence perceived note duration.[69]

As visual stimuli clearly have an impact on how music is perceived, attempting to exploit their potential in the design process appears reasonable. 'Accompanying' performer gestures such as facial expressions cannot be influenced by the designer. The gestures used to play the instrument, however, can be. Designing instrument interaction that includes carefully chosen visual components will make performances

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[64] In particular: Energy (3.1), and Transparency and Metaphors (3.2)
[65] All studies mentioned here had both musicians and non-musicians in their test groups.
[66] Steven J Morrison et al., "Conductor Gestures Influence Evaluations of Ensemble Performance," *Frontiers in Psychology* 5 (2014).
[67] Bradley Vines et al., "Cross-Modal Interactions in the Perception of Musical Performance," *Cognition* 101, no. 1 (2006): 80–113.
[68] William Forde Thompson, Phil Graham, and Frank A Russo, "Seeing Music Performance: Visual Influences on Perception and Experience," *Semiotica* 2005, no. 156 (2005): 203–27.
[69] Michael Schutz and Scott Lipscomb, "Hearing Gestures, Seeing Music: Vision Influences Perceived Tone Duration," *Perception* 36, no. 6 (2007): 888–97.

more engaging and transparent for the audience, as long as the movement appears justified in the context of instrumental play.[70]

3.5 Summary

The concepts mentioned in this chapter, energy and effort, transparency, constraints, and audience perception depend heavily on the electronic instrument designer's possibility to specifically determine the gestures that a performer uses during play. Ignoring the bodily involvement of the player during the design process will leave some of the interaction open for interpretation, possibly resulting in an apparent disconnection between performer and sound, or in unnecessary 'showmanship'. A good way to determine instrument interaction is the use of 'effective' gesture (see 1.1). By focusing instrument interaction on gestures which are necessary for sound creation, the designer has more control of the performer's movement and can thereby shift the balance between 'effective' and 'accompanying' gesture to more closely resemble its distribution in acoustical instruments. The use of *excitation* gesture is a very direct way to influence a player's bodily involvement, as it enables the designer to closely link human movement and sonic result, while focusing on the movement itself as opposed to the end result or 'target' of a gesture.

Discussion

Some of the drawbacks connected to *excitation* gesture have already come up in different contexts within this thesis, but have not yet been specifically addressed. *Excitation* gestures in expert acoustic instrumental performance are enormously complex, both in the players interaction with the instrument, as well as the physical processes in the instruments themselves. This makes the creation of similarly expressive electronic instruments a challenging task. While the designer can accurately determine the characteristics of the instrument, the interaction between instrument and performer is also defined by the physical abilities of the player and the precision of the sensors utilised. While many aspects of acoustic instrumental

[70] As opposed to appearing exaggerated and unnecessary.

play that involve *modulation* and *selection* gestures can be adequately captured using one sensor (finger position on a string; pressed key on a saxophone) the ones involving *excitation* gestures are more likely to require several sensors to capture all intricacies of the interaction. A bowing gesture, for example, contains speed, pressure, and position information (both on the string and the bow). In an ideal case this data would be captured by a range of sensors which would then subsequently be combined to define a smaller number of synthesis parameters in what is known as a 'convergent' mapping.[71] Using the data from only one sensor to control synthesis parameters connected to *excitation* often results in overly simple instrument interaction, such as the commonly occurring non velocity-sensitive sound triggering in motion controlled electronic instruments. Only once the sensor system of an instrument is capable to detect a sufficient amount nuance in play does it become possible to the performer to develop nuanced play through practice.
This drawback will likely disappear with advances in sensor technology that allow capturing more nuances of human movement.

Another drawback in *excitation*-focused approaches is the tendency to pursue transparency from an audience perspective. If we consider sound creation through the use of *excitation* gestures to be 'the hard way' as opposed to triggering and modifying pre-made sonic structures of higher complexity through *selection* and *modulation*, the former approach suggests that the audience should also be aware of the difference. It is therefore tempting to introduce potentially didactic elements, that make it obvious to the audience, that the performer is indeed the cause of individual sonic events. In the current electronic performance practice, most audiences do not expect to fully understand the inherent rules of the instrument on stage. The above-mentioned didactic elements appear in most of the *excitation*-focused instruments described in this thesis (see 1.4 and 1.5). Since *modulation*- and *selection*-heavier approaches more rarely attempt to unveil the functionality and rules of the instrument, they can fully focus on sonic complexity, versatility, and richness in interaction instead. Not having to subscribe to a particular set of distinct playing gestures simplifies the inclusion of a range of synthesis methods, thereby increasing the flexibility of the entire setup. Compared to that, an *excitation*-based approach with

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[71] Rovan et al., "Instrumental Gestural Mapping Strategies as Expressivity Determinants in Computer Music Performance."

simplicity and transparency as core themes might appear to choose showmanship over instrumental play, where acoustical instruments combine both aspects in a natural way.
The desire or need for didactic performance elements is closely linked to audience experience and expectations. It is likely to disappear once audiences are used to coherent links between movement and sound in electronic performance. Whether that will ever happen is debatable.

In the context of this thesis, the terms *excitation* gesture and *excitation* in general have been used somewhat interchangeably, blurring the lines between Cadoz' category and the broader meaning of the term in physics and sound synthesis. This implies that the performed and perceived instrumental gesture, and the resulting physical (or algorithmic) processes behind the gesture do not need to be distinguished from one another. I would argue that, in the context of electronic instrument design, they indeed do not need to be distinguished. If the aim is to create intuitive and satisfyingly complex interfaces for performers and engaging performances for the audiences, the core theme of the design process is perception. In the specific case of *excitation*, both performer and audiences should be under the impression, that the performer's physical actions cause or have influence on the sonic result. Whether believable sonic consequences of physical movement are achieved through digital models of acoustical sounding bodies (physical modelling) or any other synthesis or sampling technique is, in my opinion, not relevant. This is supported by the fact, that the underlying source of energy in the electronic domain is electricity, meaning that any other type of physical force is unavoidably a model and therefore not real.
One can additionally pose the question, whether strictly adhering to the specific definition of *excitation* gesture is necessary in order to benefit from its advantages. A good example for examining this question is the Twister analysed in Chapter 1.5. Among the movements performed on the instrument, one gesture is modelled after accordion playing: pushing together and pulling apart the two discs. This gesture is captured using an infra-red sensor and the absolute distance is used to control the volume of a randomly generated note sequence.[72] In this case the original *excitation*

[72] Ward and Torre, “Constraining Movement as a Basis for DMI Design and Performance.” p. 452

gesture of the accordion (pushing and pulling) is modeled using a *modulation* gesture (adjusting the distance between the two discs), while the timbre of individual notes is detached from any performer input. With all indicators pointing away from *excitation*, a certain fusion of gesture and sound is still present, conveying a consistent musical message in both player movement and sonic events. This suggests that approximating the rules and characteristics of *excitation* gesture can in certain cases already be enough to achieve some of its benefits.

While conceptual frameworks, such as Cadoz' Typology, can be helpful in informing and guiding the design process, strict adherence will likely result in unnecessary restrictions and stand in the way of the ultimate musical goals. Most of the practice-based research in electronic instrument design is focused on idiosyncratic approaches aiming towards solutions for individual compositional problems, with broader frameworks being utilised for the evaluation of engineering aspects of the instruments rather than the interaction design process.[73] Evaluation of the latter should include a perception-based assessment of an instrument's interaction from a performer standpoint. If the interaction does not 'feel' rich and nuanced to the player, the resulting performances will likely not be nuanced either.

A last point worth mentioning in this context is the basic question, whether electronic instruments should in any way be influenced or even restricted by the characteristics of acoustical instruments. The field of electronic sound with its myriads of sonic possibilities is vastly different from the acoustical domain and one can rightfully ask the question, why any of these fields should inform the other in any way. If the need for *excitation* is seen as an unavoidable necessity that only acoustical instruments have, there appears to be no reason to introduce it into electronic sound production and performance. This way of thinking is certainly valid for many types of electronic music, including acousmatic music with its performer-free concert practice, and audio-visual music whose main focus is on the visual elements. However, if the aim is to effectively present electronic music performance on stage, the common ground with acoustic performance cannot be ignored. This common ground includes the concept of *excitation*. 'Unnatural' or 'inorganic' ways of interacting with instruments

[73] Wanderley, "Gestural Control of Music."

can potentially favour 'unnatural' or 'inorganic' music. That is not a disadvantage, but it is a restriction to a certain type of musical expression. In the words of Atau Tanaka, a leading practitioner in the field of electronic instruments:

"*Sensor devices give us a freedom from mechanical and acoustical constraints. Despite this, an acoustic instrument is capable of responding to a player's expressive subtlety in a way we can only hope to approach with new instruments.*"[74]

[74] Tanaka, "Musical Performance Practice on Sensor-Based Instruments." p. 404

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