CHAPTER FOUR

THE MATERIAL CLARINET

SCOTT MCLAUGHLIN

What is a clarinet? What is a Buffet Legende B♭ clarinet? What is my specific Buffet Legende B♭ clarinet? What is that clarinet played by me, in this moment, and in this room? How can these different instrument-body assemblages unfold in different ways, forking-off different possibilities? In a pragmatic and doxalogical (Bourdieu-ian) sense, the answer to these questions is simple because such differences become manifest only in the subtleties observable—in most cases—by expert practitioners themselves, whether in listening to others or to themselves in the moment of playing. But what happens if we pursue the possibility that these differences can be foregrounded in ways that offer new possibilities for composition and performance? How can the individuation of the instrument, as part of an embodied instrument-player assemblage that foregrounds indeterminacy, contingency, and responsiveness be a way of rethinking the instrument?

This chapter is written as part of an AHRC (Arts and Humanities Research Council, UK) Leadership Fellowship project titled "The Garden of Forking Paths". For this project, I collaborated with clarinettists Heather Roche and Jonathan Sage, and also partnered with the Royal Northern College of Music to work with student composers and clarinetists.[1] The Garden of Forking Paths project is about composing for the indeterminacy of the clarinet: the unpredictable phenomena found across the strata and seams of clarinet sound-production, the transition points in its sonic "phase-space".[2] Alongside researching through practice, the project leans

[1] The RNCM partnership was facilitated by Larry Goves and Sarah Watts from the Experimental/Exploratory Music Research Centre (EEMRC) at the Royal Northern College of Music.

[2] "Phase-space" is a term borrowed from physics to define the set of possible states of a system, usually expressed as a 2D or 3D graph. As a simple example, the phase-space of a marble placed on the lip of a bowl might be as follows: a stable state before it begins to roll into the bowl; a rapidly changing (but stable) state of

on theory via Gilbert Simondon's concept of *individuation*, as well as on ideas of materiality and agency drawn from Andrew Pickering's "dance of [human and material] agencies" (Pickering 1995: 22) and Karen Barad's concept of "intra-action" (Barad 2007: 33), to examine how a rethinking of the instrument in terms of its individual-ness, its haecceities, affords a compositional approach where the cracks of difference between nominally fungible instruments expand into open spaces of creative possibility.[3]

The compositional practice centres on open forms where different possible paths—physical paths threading through the resonance of the instrument—reveal themselves in performance. It means moving the site of composition away from specific and controlled objects (notes, gestures, specific timbres, etc.), and towards sonic behaviours of the instrument and emergent sonic terrain, threading together the player's skills and the instrument's resonant topology so that paths of resistance and slippage are negotiated through listening and finely-tuned embodied skills. The research proceeds towards this goal by treating the player and the instrument as a single assemblage, working together in co-productive performance where the clarinet has its own material agency commensurate with that of the player. The clarinet's agency is foregrounded through a compositional process where the player follows the materiality of the instrument, and allows the instrument's response in-the-moment to determine the possible paths. The corollary of all this is that the instrument is conceived not as a tool for making notes, but as a complex physical system conjoined with the player whose approach to performance is rooted both in the dynamical topology of a clarinet in constant transition, and in the phenomenal and cybernetic traditions of experimental music and improvisation where such systems are actively engaged with in aural-haptic feedback.

In this connection, Simondon's notion of "individuation" serves to move beyond the paradigm of performance wherein the player uses the instrument to instantiate a sound as an interpretation of a notation. Instead, this project looks to the player-instrument assemblage as an emergent play of sonic forms hidden in resonant-material potentialities—the weighted but infinite lines of flight immanent in each connection of breath and reed.

---

increasing acceleration as it rolls down; periodically stable states where it rolls back and forth across the bottom of the bowl as it loses energy and decelerates; a final stable state as it sits at the bottom of the bowl, the most powerful "attractor" of the system. Among these stable states there will also be unstable and meta-stable points in the system as it transitions from one stable state to another; these are moments of unpredictability.

[3] For more on this point, see McLaughlin (in press 2021).

Simondon builds his notion of "individuation" on principles borrowed from the biological process of individuation, where the contingent unfolding of chemical-material potentials determine the specifics of an individual cell. Stem cells are well known examples of this; equally relevant is the way every Zebra's stripe pattern is individual but emerges from the same cellular potential—the infinite variety of snowflakes and clouds is also pertinent here. For my argument, though, the idea of emergence from potential is not sufficient: I invoke Simondon because his concept of individuation takes the radical step of not working backwards from the stable final form, not "accord[ing] an ontological privilege to the already constituted individual" (Simondon, in Mills 2016: 10). For Simondon, as Bardin and Menegalle describe, "Individuation is a process which never determines a definitive state, but only a temporary resolution to a set of evolutionary instabilities" (Bardin and Menegalle 2015: 15). Musically and compositionally speaking, this approach necessitates a move away from representational thinking and towards the interaction of states and systems, supported by an embodied approach to the instrument that valorises listening, responsiveness, and openness to the unfolding potential that continuously becomes something else—to borrow Paulo De Assis's words, "becoming-something is not becoming-this, but always becoming-something-else" (De Assis 2017: 698).[4]

In this chapter, I outline a view of the instrument that ignores western music theory's basic doxa of pitches and notes in favour of treating the clarinet as a superimposition of multiple resonant tubes. In this model, each fingering configuration offers a different resonant landscape to be explored through a flexible range of embodied techniques, such as overblowing and underblowing, that may afford results across a spectrum of monophonic and multiphonic sound behaviours. The final section of the chapter outlines how these possibilities lead to compositional methods that—in my case—favour responsive approaches to instability and indeterminacy, requiring the player to listen very closely to the material agency of the instrument in order to follow the forking paths of each landscape where "ongoingness" (Haraway 2016: 11) is performatively co-constitutive.

In the following section, I outline the techniques of clarinet playing as a physical system in an embodied instrument-player assemblage. Firstly, I

[4] Using Simondon's concept of "transduction", De Assis focuses on virtuality and potential in performance. He describes "transduction" as "Simondon's key concept for understanding processes of differentiation and of individuation … [referring] to a dynamic operation by which energy is actualized, moving from one state to the next, in a process that individuates new materialities" (De Assis 2017: 695).

reframe the clarinet as a complex physical system by outlining a compositional practice grounded in the materiality of the instrument and its sonic phenomena. Specifically, this focuses on resonance phenomena, eschewing externally fixed pitch systems in favour of treating pitch as an emergent property of Baradian intra-action[5] between embodied performance techniques of the clarinettist and the physical resonances of the clarinet. Here, the clarinet is taken to be a multiple, where each different fingering configuration is a similar-but-essentially-different instrument. In other words, it is conceptualized as a dynamic manifold of fingerings and registral resonance spaces. This manifold is traversed by the player using embodied skills to activate different features of each fingering's resonant topology. Secondly, I use Simondon's notion of "individuation" alongside Haraway's concept of "ongoingness" to discuss the consequences of emergence, on continuous sound and reciprocity in the player-instrument assemblage.

The Dynamical Clarinet

The Garden of Forking Paths project treats the clarinet as an "ongoing" instrument, where the player and instrument work together to maintain conditions for emergent sonic phenomena to carry on. Not just continuous sound as an aesthetic quality, but as situatedness—the composed situation that engages with the ongoing mutual feedback of player and instrument in their materiality. Echoing anthropologist Tim Ingold's assertion that materiality is "a process of *working with* materials and not just *doing to* them [original emphasis]" (Ingold 2011: 10), this project investigates the clarinet, and clarinettists, in order to compose *with* the clarinet, writing *for* its indeterminacy. This is not simply eliciting unexpected sounds, but repeatedly circling and exploring unstable zones of sound production to see where indeterminacies can lead. The clarinet, the instrument in your hands in the moment of performance, is the garden where paths fork.

Composing for ongoingness must engage the player and the composer with the embodied materiality of the player-instrument assemblage, i.e. the dynamical complex system of continuous minute adjustment to the ongoing flows and resistances of the assemblage. The player-instrument assemblage is like other complex systems in this regard: the flow of water as it

[5] Karen Barad's concept of "intra-action" "signifies the mutual constitution of entangled agencies. That is, in contrast to the usual "interaction", which assumes that there are separate individual agencies that precede their interaction, the notion of intra-action recognizes that distinct agencies do not precede, but rather emerge through, their intra-action" (Barad 2007: 33).

transitions from smooth stream to swirling rapids; the flickering, floating, and diving of the global monetary system responding to uncountable human and corporate forces; the geological contingency of rivers carving through landscapes, shifting from bed to bed over millennia as it negotiates the shifting earth, the grains, soils, sands, shales, strata, tables, plates, all constantly in motion at every scale. The science of understanding such systems is the field of physics called "dynamical systems theory" (also known as "chaos theory"), and it is through the language of such systems that the clarinet will be reframed here, grounded in acoustical knowledge of the instrument.

At the outset, this may appear to be a project of alienation, but the true goal is to reach a point where the dynamical system is shown to be already immanent in clarinet performance techniques, requiring only a shift of perception to foreground the beauty of inherent contingency. Rather than thinking of this as "extended technique" that moves away from the centre of performance, think instead of an in-tensive view that brings everyone—the player, the listener, and the composer—further inside the instrument, stripping away layers of imposed musical abstractions to reveal the complex eddies and flows of the materially dynamical clarinet, the Heraclitian river that the player steps into every time they engage the instrument.

The first conceit adopted by this approach to composition is that fingering configurations are the primary material, rather than abstract pitches. Each fingering configuration defines a set of resonances of varying strengths, and multiple ways that these resonances interact with each other—both positively as multiphonics of various types, and negatively as resistances and "voids" (where spaces resist combination because the transition zone is too unstable). The resonances of each fingering configuration are arranged by register, generally conforming to the well-known clarinet registers:

- The lowest register is the "chalumeau" (E3–A#4)[6]

---

[6] All pitch names in this chapter are transposed into B♭. Clarinet fingerings discussed in this chapter use the following naming convention for holes and keys. Holes are referred to as LH1/LH2/LH3 for left-hand holes (where 1 is index finger) and RH1/RH2/RH3 for right-hand holes. Other keys are named for their most common chalumeau pitch usage: e.g. the lowest right-hand trill key is called "E Clarinet fingerings discussed in this chapter use the following naming convention for holes and keys. Holes are referred to as LH1/LH2/LH3 for left-hand holes (where 1 is index finger) and RH1/RH2/RH3 for right-hand holes. Other keys are named for their most common chalumeau pitch usage: e.g. the lowest right-hand

- The middle is the "clarino" (or "clarion") register (B4–C6)
- The extendable upper is the "altissimo" range (starting at C#6)

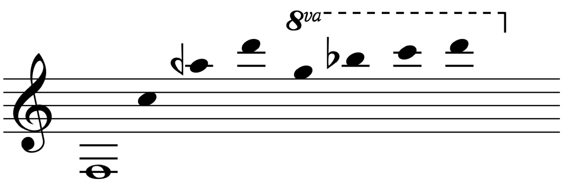
Practically all fingerings have one resonance in each of the chalumeau and clarino registers, and multiple resonances in the altissimo. As I will show later, especially in the context of multiphonics there is a break between chalumeau and higher registers, essentially the difference between a relatively stable fundamental resonance in the chalumeau and a variable sea of higher resonances above this fundamental competing for emergence and presence. It should be stated at this point that this project does not attempt to exhaustively categorise the resonances of every fingering, but rather engages with general principles, and families of behaviour, that allow a player to work responsively with material contingency. In this sense, this chapter outlines the tendencies of the clarinet as a multiple of resonant topologies, and the embodied techniques of the player used to actively traverse these spaces.

Underlying this centering of fingering configurations is an understanding of the clarinet as a tube, or rather as many tubes superimposed. The clarinet body is a (mostly) cylindrical (usually) wooden tube, closed at one end by the reed. The body of the clarinet defines the main resonances by facilitating columns of vibrating air of different lengths, controlled by opening and closing holes along the body (fingering configurations). Hereafter, I refer to the various columns of vibrating air as "tubes": each of these tubes has a set of resonant frequencies defined by the length of the column of vibrating air that starts at the reed and ends at the "terminator hole", which is the lowest open tone hole; or the clarinet bell in the case of the lowest written pitch E3. The lowest open tone hole provides one chalumeau resonance (and its harmonics in other registers), but the resonance is also influenced by any other open holes, where the clarinet is "forked" by opening additional holes above the lowest one: this will be discussed later under "loading" and "venting". The following section begins with some straightforward clarinet mechanics to ground the phenomenal and dynamical model of the clarinet, described from the perspective of the author—a composer as well as an amateur clarinettist. The intention here is to lay out the physics of the instrument largely in terms of stable sound production and ideal possibilities, to set up a later discussion of its less stable spaces where indeterminacy is more prevalent.

---

trill key is called "E♭ trill key". Additionally, this chapter refers only to transposed pitches (in B♭), not sounding pitches. trill key".

The most simple clarinet is an unforked tube, where there are no open holes between the terminator hole and the reed: the standard chalumeau pitch fingerings are mostly unforked tubes. These tubes provide a strong chalumeau register resonance, and can also be overblown (an embodied performance technique) to produce harmonics of that resonance—note that clarinet harmonics do not conform to the standard natural harmonic series, often being flatter to a significant degree. These harmonics may be connected in different ways as multiphonics in some cases. As an example, the F3 fingering can be overblown to produce the harmonics shown in Example 4-1. Note that this example should be taken as potential only, since the actual results are dependent on the player and the setup (reed, mouthpiece, etc.). Harmonics are a standard technique but get more difficult and less stable as you go up in pitch. This provides a (simplified) phase space for the tube, a set of resonances that can be activated and connected through embodied techniques of overblowing and the careful balancing of pressure and embouchure tuning.



Example 4-1. Harmonics of the F3 tube.

On the unforked tube, in addition to playing single tones, the technique of overblowing can be carefully nuanced to produce two types of multiphonics: spectral multiphonics, and harmonic multiphonics. In spectral multiphonics, multiple partials of the series are sounded together as a single fused percept. Through embouchure manipulation, it is possible to filter this to emphasise a specific partial or sweep through the spectrum. This is a reasonably well-known technique that only really works on the longest tubes, and it is more effective on the bass clarinet. Harmonic multiphonics are the sounding of the fundamental and one of its low-order harmonics (such as the 3rd or 5th partial, which will be significantly more flat than the ideal harmonic series indicates). Normally, this only works slowly and at low dynamics, and is difficult to balance and stabilise. This is not a standard technique and is highly dependent on setup and player. Simple overblowing is already quite a flexible technique, but the clarinet mechanism has additional possibilities in "venting". One of the key steps in the development of the modern clarinet at the end of the seventeenth century was the invention of the register key, which opens a small-bore hole approximately one-third of the way down from the reed. The register key acts as a "vent" that releases air pressure and suppresses the fundamental resonance of the tube, allowing the next strongest resonance (usually the 3rd partial, a 12th higher than the fundamental) to sound.[7] This opens up the clarino register (B4–C6) without the need for overblowing, but overblowing is still effective to extend into the altissimo register on the same fingering: the register key can also make altissimo overblowing more stable. Overblowing is the primary embodied technique used by clarinettists to extend the pitch possibilities of any given fingering by shifting the resonance of the tube into different registers; either using an embodied technique alone (embouchure, air-flow, throat-tuning etc.) or opening vent holes such as the register key.

When the strong resonance is in the clarino register or higher, the system also affords "underblowing" as a way to circumvent the supressing effect of the register vent; this has consequences for pitch and timbre as will be discussed below. Underblowing is not a standard clarinet technique; it is rather something that clarinettists learn to avoid when they first learn to play in the clarino and altissimo registers, since attempts to play higher registers often result in unintended multiphonics until the student learns the correct embouchure and pressure (diaphragm support). So, rather than an extended technique, this is more of a "reclaimed" technique, now achieved through control instead of accident. In the clarino register, the same F3 fingering discussed above, now with the addition of the register key, has its strongest resonance as the clarino C5. Overblowing this fingering still gives the same harmonics as the F3 fingering, since it is the same "tube",[8] only now vented by the register key, which alters the strength of some harmonics. Since the strongest resonance is not the chalumeau register fundamental, this register also opens up the possibility of underblowing to access the chalumeau. Underblowing requires a fairly

[7] For an excellent layperson's guide to instrument acoustics, see the Music Acoustics website, the School of Physics, The University of New South Wales, at <https://newt.phys.unsw.edu.au/jw/clarinetacoustics.html#registerhole>.
For a more detailed technical explanation, see Fletcher and Rossing (1998).

[8] Here, I adopt the nomenclature described by Thomas Bergeron to refer to the fundamental air column. For example, the fingering for A3 gives the air column stretching from reed to the open hole at RH3 (right-hand 3rd finger). Opening the register key (or similar vent) alters that fingering to produce harmonics of that fundamental (with altered intonation usually). The "tube" concept focuses on the physical resonance of the instrument. See Bergeron (1989: 49).

extreme embouchure position to suppress the dominant resonance in the clarino and reveal the chalumeau pitch. The resulting underblown pitch tends to be breathy, ameliorated, and quiet.[9] Also, the resulting chalumeau pitch is not simply the F3 fundamental—it may be slightly or significantly higher depending on distance from the register hole. While underblowing functions well from fingered E5 (A3 tube) to C6 (F4 tube), it is not effective with long tubes; consequently, D#5 and D5 can be very stubborn, and anything below that (such as the C5 in Figure 4-1) is almost impossible to usefully underblow. An underblown B5 produces a slightly sharp F#4, a whole tone higher than the expected fundamental E4. However, an underblown D5 produces a C4, a fourth higher than the expected fundamental G3. The C5 example given above is actually extremely difficult to underblow, producing, sometimes, an almost inaudibly breathy B3. With appropriate nuancing of embodied techniques, multiphonics can be produced between (usually) the underblown pitch and one or more non-chalumeau pitches. In fact, as will be discussed later, this is the way the vast majority of multiphonics are produced. Underblowing relies on "loading", and works well with mid-and upper clarino fingerings, but comes into its own with forked fingerings such as altissimo fingerings; this will be discussed later in the context of "loading". As well as underblown pitches and multiphonics, overblown multiphonics are also possible in the clarino register.

In terms of standard fingerings for chromatic pitches, the chalumeau and clarino registers mostly have only a single canonical fingering for each, with individual players developing some additional homebrew fingerings for specific intonational or timbral requirements (often referred to as "shading"; see "loading" below). The higher the strong resonance required, the larger the pool of possible different fingerings, the latter exploding once we enter the altissimo register (from C#6 upwards). Strong resonances in this register have a dizzying array of fingering possibilities but very unevenly distributed; some pitches around G#6 have anything from 18 to more than 30 known fingerings, while from about C#7, this thins out again to one or two per chromatic pitch as the limits of the clarinet's resonance are reached.[10] Fingerings with a strong altissimo

---

[9] This is due to the extreme embouchure position required, and also to the effect of the register hole suppressing the fundamental as the tube becomes longer. This effect varies depending on how close the register hole is to the fundamental's point of maximum pressure.

[10] For examples of the breadth and variety of altissimo fingerings, see Woodwind.org at <https://www.wfg.woodwind.org/clarinet/cl_alt_4.html>, or Sim (2008).

resonance can be underblown to produce a chalumeau component in practically all cases, and in the great majority of cases there is also a clarino component available, which sometimes can be sustained alongside the altissimo component.

Both the standard technique of overblowing, and the less standard technique of underblowing can be balanced in different ways to produce multiphonic sound (see below). The three strong resonance registers of the clarinet (chalumeau, clarino, altissimo) can be held in balance through careful positioning of embodied techniques. Sometimes all three can combine as multiphonics, but usually two resonances will create the primary interaction, with other registers and heterodyne components[11] being present to varying degrees: the registers tend to combine as either chalumeau + altissimo or chalumeau + clarino components.[12] The construction of multiphonics has been discussed previously by other scholars in terms of the heterodyne components, but it is often taken for granted that there is no way to derive the pitches of a multiphonic from its fingering: some scholars have also pointed to the same mechanism that I outline below.[13] While it is certainly true that highly specific pitch predictions are difficult if not impossible (due to the complexities of filtering in both the heterodyne components and harmonics), it is definitely possible for many fingerings to yield quite specific predictions for the chalumeau components of a given fingering, and to suggest probable pitch areas for harmonics in clarino and altissimo registers. This will be detailed further below with some examples, but first, it is important to discuss the techniques of "loading" and "venting".

Loading and venting

"Loading" and "venting" are both techniques for altering or generating fingerings outside the standard set. The concepts will be familiar to all wind players, but I am specifically referencing the terms as proposed by saxophonist Thomas Bergeron in his 1989 DMA thesis *Saxophone*

---

[11] Heterodyne components are similar to sideband frequencies of modulation synthesis (combination and difference tones), and are a key aspect of the electronic-sounding quality of multiphonic timbres when fully fused. See Backus (1977), and Gottfried (2008).

[12] Heather Roche has also found a limited number of unusual fingerings where the clarino+altissimo can combine, but not the chalumeau. See, Roche (2019).

[13] I was only able to find the same mechanism described in English in relatively old texts, the earliest being Ronald Caravan's DMA thesis (1974: xi–xii). In French, it is demonstrated and discussed more recently by Alain Sève (1998).

Multiphonics: A Scalar Model. Bergeron's research addresses a gap in knowledge between the well-known research strand that develops "descriptive catalog[ues] of multiphonics" and those that seek to understand the "underlying principles of multiphonic tone production and the potential of generating series of multiphonics with definable relationships" (Bergeron 1989: 2).[14] As such, my own research follows directly in Bergeron's path by examining these underlying principles for the clarinet, and differs from it by focusing on open-ended indeterminacy based on the materiality of the instrument. As well as this focus on physicality, Bergeron's approach also valorises the player's learned skills and cultural practices. He fuses an acoustic understanding of the instrument as columns-of-air with the knowledge of the player that is fundamentally based on abstractions of pitch and key. Bergeron's system is framed in relation to common reference points understood by all players, avoiding alienating the players by asking them to reimagine their instrument in terms of physics.

The term "loading" is Bergeron's,[15] and while the technique itself is well known to wind players as a way of altering intonation or colour (sometimes called "shading"), both Bergeron's and my own research seek to extend this approach into a generative technique in its own right. Loading is achieved as follows. Beginning again, as above, with the unforked tube (e.g. standard C4 fingering with holes T/LH1/LH2/LH3 closed, and all RH holes/keys open), loading involves closing additional holes/keys below the C4 terminator hole (see Figure 4-1). The C4 tube (the C4 column of vibrating air) ends at the RH1 hole, where the majority of the sound emerges, but the nature of the sound waves means that the vibrating column of air extends slightly past that point as it dissipates from the pressure change at the hole. This is known in acoustics as "end correction", meaning that the real pitch obtained at that hole is slightly flatter than the theoretical pitch suggested by physical measurement of the tube.[16] In normal conditions the pitch of that fingering is also dependent on the remaining tube below this hole; if the lower end of the clarinet was simply removed, then the pitch would again become sharp. When the fingering is loaded by closing additional holes downstream (below the open hole) they create longer sections of closed tube below the open hole;

---

[14] Bergeron's ideas build on those of Ronald Caravan (1974) and flutist Robert Dick (1975).

[15] Bergeron credits Dr Kwangjai Park, Department of Physics, the University of Oregon, for the term (Bergeron 1989: 59).

[16] Of course, this flattening is assumed by instrument builders. It might, therefore, be more accurate to say that if there was no end correction (and assuming the holes were in their normal positions), then clarinet notes would be sharp in general.

and the pitch is flattened because the end correction is further extended by these additional sections of closed tube, essentially dragging the pitch down by loading it with additional resonant space. Loading effects are not linearly distributed along the instrument, with some keys and holes having substantially different effects. The closer the loading is to the open hole, the more significant the flattening effect. This effect is clear in the (mostly) unforked tubes of chalumeau and clarino register pitches; but, altissimo register fingerings above this are mostly forked, and it becomes difficult to identify the basic fingering against which the loading can be counted. Additionally, the relationships between harmonics are complex in that register, and it is not easily predicted whether adding a load key will flatten a pitch or cause a leap upwards to the next harmonic, which will itself be flattened. In my research, I prefer to think about loading as only meaningful in the chalumeau context, the reasons for which will become clear when discussing "venting".

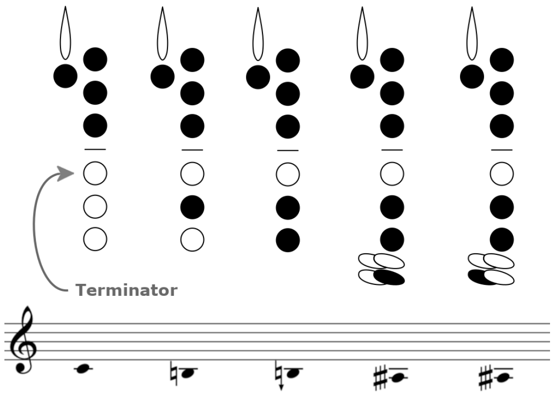


Figure 4-1. Loading C4, showing the terminator hole (the primary hole through which pitch escapes) and the effect on pitch of increased loading.

Compared to loading, "venting" is arguably a better understood technique in wind instruments, since it is the basic technique for facilitating easier overblowing into higher registers; nevertheless, the term itself has significantly more use in acoustics.[17] For example, the register key is a vent that suppresses the fundamental resonance of the tube and allows the third partial to be easily overblown. The register key is the best

[17] For clarinettists, the term "venting" is more often used in a different context to indicate "shading" and colour effects on intonation or timbre.

known vent, but in truth every hole on the clarinet is a vent: for example, standard fingerings for altissimo C#6–D6 use LH1 as a register vent for the 5th partials of the A3–B♭3 tubes. For this research, conceiving every hole as a vent opens up a range of productive possibilities, which will be explored further after an initial discussion of basic venting in relation to both loading and more standard techniques.

In Bergeron's research, venting means opening additional holes upstream from the terminator hole, which can have two effects (see Figure 4-2): (1) facilitating overblowing as above, and (2) a kind of reverse loading, sharpening the pitch.

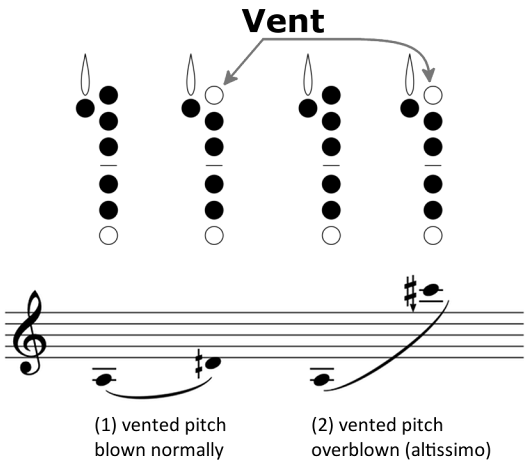


Figure 4-2. Two effects of venting: as reverse-loading, and as overblown register hole.

The "reverse loading" perspective causes some confusion. Essentially, any fingering can be described in terms of venting by opening holes upstream in relation to the lowest open hole, or loading by closing holes downstream. Figure 4-3 shows the same fingering resulting from venting a C4 fingering, or loading an E4 fingering: the resultant pitch is the same in both examples, of course.

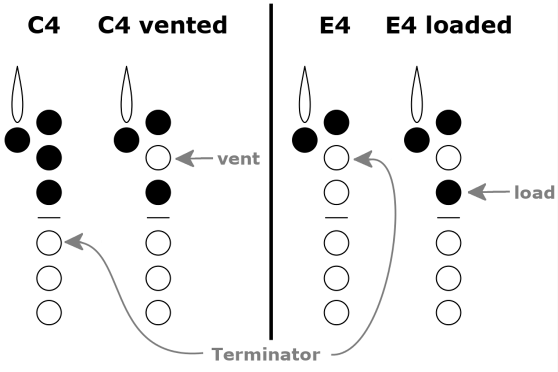


Figure 4-3. Venting in chalumeau/clarino registers as loading in reverse.

Because of this potential for confusion, I find it more sensible to discuss loading in relation to the terminator hole only, and mostly in relation to chalumeau and clarino pitches. For any given fingering, the lowest pitch available is the air column between the reed and the terminator hole. In the case of Figure 4-3 the fingering derived from either venting C4 or loading E4 has its first open hole at LH2, giving a pitch of E4 -30¢ (approximately). That same fingering can be overblown to produce various harmonics, with the loading tending to have a larger effect on the clarino by flattening it further.[18]

Taking this approach to its logical conclusion also shows how underblown pitches are derived, essentially by taking the register key as the fundamental tube, variably loaded by additional closed holes downstream. Clarino register fingerings use the register key to suppress the fundamental and emphasise the 3rd partial. Removing the register key restores the fundamental, but as seen above underblowing the clarino fingering does not produce the fundamental but an entirely unrelated pitch. This can be explained by loading. As Figure 4-4 shows, A3 can be overblown to its 3rd partial E5 using embouchure technique, but normal practice would be to open the register hole to afford easy production of E5 by suppressing the fundamental A3. However, with the register key open, underblowing the fingerings produces C#4, not A3. The easiest explanation is that this results from the register hole being loaded by the

---

[18] This is easily demonstrated by playing E4, then adding register key to overblow to B5, then loading this as shown in figure 4-4 with LH3. Benade shows how higher harmonics have more exaggerated end-correction, which leads to stronger effect and more flattening. See figure 21.1 in Benade (1990/1976: 432).

six closed holes of the fingering, thus significantly flattening the pitch: because the register key is now the terminator hole (the first hole open downstream from the reed), that hole generates the chalumeau pitch. To demonstrate this, with all fingers off and the register key open, a slightly sharp G#4 is produced; then, closing one-by-one all the remaining holes of the A3/E5 fingering, the pitch is gradually flattened to C#4. There is also a radical change in timbre as the added load keys drag the air column into the lower part of the clarinet, requiring more air and a change of embouchure to keep the lower pitch stable and resist the 3rd partial emerging.

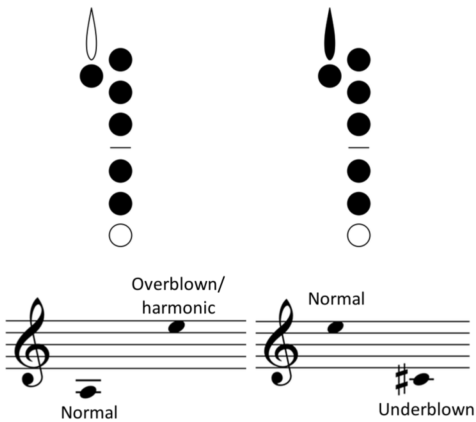


Figure 4-4. Loading of register hole by closed holes downstream produces the underblown pitch, unrelated to the fundamental of the overblown tube.

Thus, for chalumeau pitches it is appropriate to talk about loading in relation to the terminator hole: in this context, the loaded pitch can be understood as the result of the column of air between reed and terminator hole made longer, through the action of end-correction by loading with closed downstream holes. For higher pitches, venting is the first technique to consider, with a secondary flattening effect by loading that may also be relevant. This combination of loading and venting generates different pitches in the chalumeau register and higher registers, leading to a discussion of multiphonics as a balancing of these registers in a single complex sound.

Multiphonics

Multiphonics are commonly discussed as requiring "special fingerings", but as I hope the preceding has demonstrated, every fingering has multiple possible resonances that can potentially be played simultaneously. The rhetorical position of "special fingerings" is understandable in contexts where only the most stable and reproducible multiphonics are required, but that is not the case in this project. Multiphonics are often described as the result of two columns of air vibrating (and interfering) in the same instrument body, that is, two simultaneous tubes.[19] Clarinet multiphonics are almost always identifiable as a chalumeau pitch and a clarino or altissimo pitch (or multiple); as well as complex fused heterodyne components that make up the characteristic timbre. The prominence of the chalumeau and upper register pitch are a result of different ways those two tubes are generated. For the chalumeau register, the highest vent (i.e. the terminator, the first open hole below the reed) defines the length of the air column to the reed, and thus the pitch. Clarino pitches (and above) are—in most cases, but see below—defined instead by overblowing the lowest closed hole, where the vent(s) act to suppress fundamentals and strengthen one or more harmonics. As an example, Figure 4-5 shows a typical single-fork multiphonic fingering: here, an F3 fingering is forked by opening the left-hand C# key to add a single upstream hole.[20] This open C# hole (positioned almost halfway along the instrument) is the first hole open below the reed so it sets the chalumeau pitch as C#4, which is flattened by the additional loading of the right-hand holes closed below the C# hole, settling on a slightly sharp B3: in Figure 4-5 this is the left air column. The next prominent pitch of the multiphonic is the quarter-flat A5, which is the 5th partial venting of the F3 fingering, with its air column extending almost all the way to the end of the clarinet, as shown to the right in Figure 4-6. As mentioned previously, not just the register hole but any open hole can act as a vent to suppress the fundamental and allow a harmonic to emerge. The cylindrical shape of the clarinet bore means that odd-numbered harmonics are most significant, and the C# hole is positioned near enough to the antinode of the F3 column's 5th partial so that it acts as a vent for that partial, emerging as a prominent quarter-flat A5 and suppressing the F3 itself.

---

[19] For example, see Raasakka (2010: chapter 4.1).

[20] Note that C# is one of several press-open keys; pressing it opens a hole, unlike the other holes in this example, which are all closed by a finger (or press-close key, in the case of the F3 key itself).

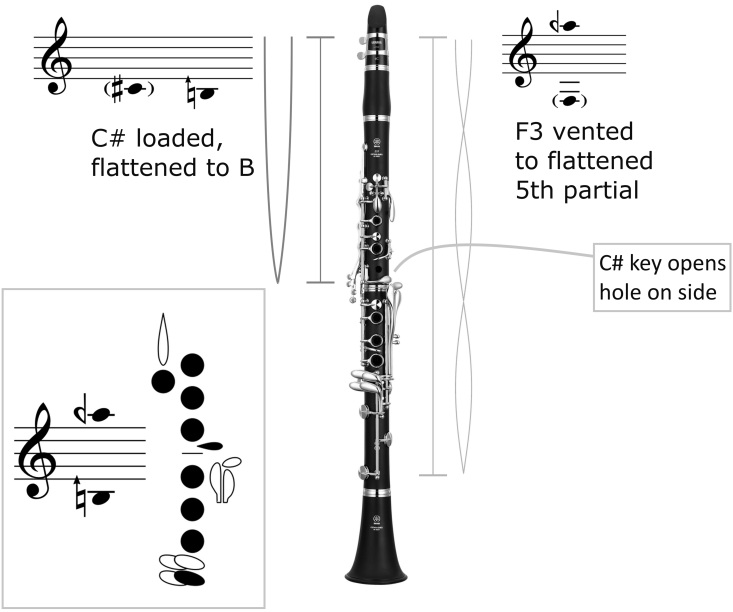


Figure 4-5. Multiphonic as two vibrating columns of air, separating chalumeau and higher pitches.

Note that the quarter-flat A5 is the actual 5th partial of F3 on the clarinet,[21] which is flatter than the expected 5th partial of A -14¢ but not because of loading. Loading only significantly acts on the pitches derived from the column of air between the reed and the C#4 hole—that is, the odd-numbered harmonics of slightly sharp B3, because that column of air is "loaded" by the extended tube created when the right-hand holes below C#4 are closed. The harmonics generated from venting the F3 tube are a different column of air which co-exists-with and interferes-with the B3 column. The relationship of the A5 to F3 can be demonstrated by playing the given fingering and isolating the quarter-flat A5 using embouchure, then releasing the C#4 key to close the vent and return to a standard F3 fingering, which—with a slight embouchure adaptation—will still sustain the quarter-flat A5, albeit with a very small intonation shift.

[21] Clarinet harmonics are always flatter than the ideal harmonic series, often to a significant degree. See Raasakka (2010: n.p.) for examples of clarinet harmonic series.

Expanding out from the example given in Figure 4-5, any hole upstream of the lowest closed hole can act as a vent, and different vents may reveal different partials.[22] That said, it is not a trivial matter to deduce what harmonic will be revealed by venting. There are several reasons for this ambiguity: multiple harmonic antinodes may be near the same vent, there may be several vents competing, or there may also be competition from harmonics of the other air column (though the longer column seems to dominate and suppress the harmonics of the shorter column). Additionally, when venting is used as part of a standard technique to stabilise a pitch, this is usually done as a half-hole,[23] since opening the hole fully tends to sharpen the pitch: intonation can also be altered using different vents on the same fingering.

As an example of interacting resonances, Figure 4-6 shows how the resultant pitch can be an indeterminate product of an apparently linear process of loading. In the diagram, chalumeau tubes are indicated by the square bracket on the left of the fingering and clarino on the right. The stave includes notes in parentheses, indicating non-sounding pitches. Note that as the loading increases from left to right, the A5 (3rd partial of D4, overblown by register key) is initially flattened by the increased loading, but then in the final two examples the sounding pitch leaps upwards rather than continuing downwards. In this example, rather than continuing to follow the loading pattern of a flattening 3rd partial of the chalumeau, the descending 5th partial of the lowest closed hole leaps to prominence. This is probably the result of two processes: the increasing length of the loading column collapses the overblown (loaded) D4 tube, and the same, increasing length means that the LH3 hole becomes an ideal vent for the lowest closed hole. As the 5th partials of the lowest closed hole descends,

---

22 This may be limited to odd-numbered partials, but I have not found a clear answer for this in my research.

23 The register hole is significantly smaller than most tone holes, because it is primarily used as a vent. The basic vent function of suppressing the fundamental is effective because low frequencies are "short circuited" by any open hole as the pressure change reflects the sound-wave back up the tube. However, high frequencies are not affected by this, as the register hole allows higher frequencies to form standing waves in the tube while blocking lower frequency standing waves. Half-holing is more effective as a vent to suppress chalumeau/fundamental resonance, but for multiphonics the half-hole is not always advisable since the chalumeau pitch is usually desired as well as upper harmonics, and fully open holes can be more effective, even though I have not researched this point extensively. Lastly, half-hole venting produces the pure harmonic, but opening the hole alters the intonation significantly, usually sharpening the pitch. Regarding acoustics of register holes, see Wolfe (n.d.).

there may also be a formant resonance—or strong frequency area—formerly occupied by the 3rd partial of the chalumeau, allowing a flip from one air column to the other. This switching process is common in higher pitches as the different resonances of the two air columns compete by suppressing or reinforcing each other unpredictably. It is possible to make educated guesses about the higher pitches that might be present, but impossible to say for sure which will emerge. Equally, small changes to fingering (as above) can retain the same approximate formants as when the fingering is altered, but can unpredictably switch to another resonance as the formant and harmonics move around.

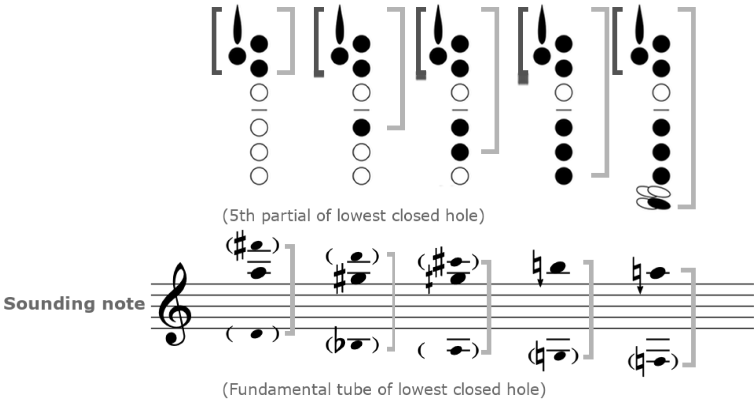


Figure 4-6. Interaction of loading and venting in monophonic sound.

Since multiphonics involve the interaction of two tubes in the same space, predicting the salience of partials above the fundamental is difficult: this area requires proper empirical research by acoustics specialists to unpick the nuances of interacting resonances. The example above of the single-forked F3 tube is reasonably straightforward in assigning the principle chalumeau and clarino resonances audible in the multiphonic. The next example is a double-forked fingering where my assertions are necessarily more speculative, but nonetheless should be useful as a possible solution.

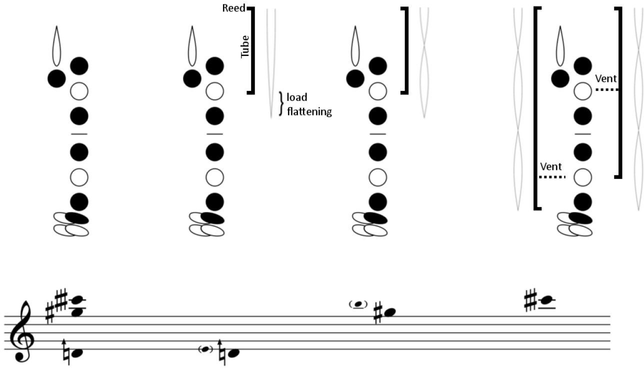


Figure 4-7. Deconstructing the multiphonic—pitches in parentheses are before loading is applied.

Example 4-7 is most simply described as a standard G#3 fingering with LH2 and RH2 opened. The chalumeau pitch derivation is straightforward. As above, the tube from reed to terminator hole provides the initial chalumeau pitch (E4), which is then flattened to a (slightly sharp) D4 when loaded with the other closed holes to complete the fingering. The example at Figure 4-6 derived the clarino pitch as a harmonic of the lowest closed hole, and applying that method here suggests that either LH2 or RH2 could be acting as vents for a harmonic of the suppressed low G#. This is where things get complex. Testing out these two holes as half-holed vents shows that both vents allow the 5th partial (C6) and the 7th partial (F6). However, with either of these holes fully opened (as in the multiphonic) RH2 produces pitches significantly sharper than LH2, which matches more closely the high pitch of the multiphonic. So what is LH2 doing? It is possible that LH2 is acting as a vent on a third tube, one that starts at the reed and terminates at the RH2 hole. In this case, the RH2 hole (A3) can be half-holed to C#6, with the fully opened hole making it very slightly sharper. Then, adding back in the bottom two closed holes (RH3 and G#) still produces C#6: adding RH3 alone suppresses C#6, but the G# key brings it back. Perhaps this means that there are two tubes reinforcing each other to produce that C#6, or does it mean that this third tube is either being suppressed by the G# tube or vice versa? The real reason is unclear without more detailed empirical testing.

Lastly, the multiphonic also contains a prominent G#5 clarino pitch. This is an interesting case where the chalumeau tube is possibly being overblown as well as producing the chalumeau pitch. The G#5 could be a product of the chalumeau D4, as its 3rd partial A5 is flattened more by loading: this is supported by the fact that clarino pitches are more prominently flattened by loading (including a noticeably larger effect from more distant closed holes that might not effect a chalumeau pitch), and that the same fingering with added register key, loaded as in Figure 4-8, produces the same G#5. The G#5 has a shadowy quality and is tricky to isolate from the multiphonic, which is consistent with a pitch that normally expects the register key to support it. When the register is added to this fingering, the G#5 and higher pitches are largely unaffected, apart from some timbral heterodyne components, with the chalumeau component sharpening significantly, as would be expected (see Figure 4-5). The case is made more ambiguous because when playing, it is possible to smoothly slide between the G#5 and the C#6 as though they were on the same harmonic series, but that seems unlikely if they are generated by different columns of air. A further twist to this is that the C#6 is then quite difficult to sound as part of the fully fused multiphonic, which implies that it is in fact a separate column; or perhaps, it is simply incompatible with some mid-range components of the sound. The mechanics are unclear. All of this is to say that this approach to deducing multiphonic pitches from their constituent tubes is complex and speculative, but not unproductive.

So what can we know from these techniques, and to what level of specificity? The chalumeau pitch of any fingering is completely predictable. It would be a trivial matter to prepare a table of all resultant pitches from combinations of tubes and loading.[24] In the clarino register a similar table can be made but whether that table will be accurate for any given fingering is less clear; but at least it offers a possible starting point. For altissimo pitches the information is less specific. The possibilities can be narrowed to a few options but could easily be a semitone or more off. Assuming that the lowest closed hole is a suppressed fundamental suggests that the 5th or 7th partial will be present, but it is hard to know which will be more likely. Additionally, the intonation of the partial may not conform to the ideal; intonation can be altered depending on the vent position, possible loading effects, and other unpredictable interactions.[25] I would be very interested

[24] The Garden of Forking Paths project has a video of examples covering a significant percentage of this space, but has not at the time of writing produced an exhaustive table of data. <forkingpaths.leeds.ac.uk>

[25] In the context of common-practice music, clarinet intonation can be extremely nuanced, but when we step out of that into multiphonics and non-standard fingerings, intonation is often at the mercy of the instrument's materiality. Multiphonics require highly specific balances of embouchure and breath, so the

to see if further empirical research might uncover some generalities that make the picture clearer.

I hope this knowledge may be of use to composers and performers. For some readers, there will be more work to do on cataloguing and specifying to enframe the material clarinet better in the ontology-of-notes. However, for me, the very lack of specificity opens up a rich compositional research space to explore the varied topology of determinacy and indeterminacy in the clarinet phase-space; this will be outlined in the final section below. To summarise the preceding section, I presented a collection of embodied techniques for traversing the phase-space of the clarinet as a non-linear manifold of interacting resonance phenomena across a range of stability: loading and venting as techniques of the fingers; overblowing, underblowing, and balancing multiple simultaneous resonances as techniques of embouchure and breath. These techniques begin from ideas familiar to the player—now foregrounded by removing the usual trappings of pitch-systems—then proceed into a realm of acoustic phenomena and aural-haptic feedback with the instrument. The final section of this chapter outlines this phenomena as an aesthetic approach to composition that takes this contingency and lack of specificity as its ground.

Ongoingness and individuation

> In choosing a particular fingering, the saxophonist does not, as is sometimes erroneously assumed, choose a pitch. Rather, the player, by executing a fingering, establishes a resonance spectrum, which is to say he or she chooses a spectrum of potential pitch relationships. … It is the player's task to select, from among the possibilities, the desired sonority, be it monophonic or multiphonic. (Bergeron 1989: 53)

Bergeron's research in 1989 is written as a response to the dominant mode or researching multiphonics, what he described as "developing … a descriptive catalog of multiphonics" (1989: 2). He characterised his own work as "explor[ing] the underlying principles of multiphonic tone production, and the potential of generating series of multiphonics with definable relationships" (ibid.). Bergeron's move to centre the instrument on its sounding materiality, rather than in relation to external musical systems, is the starting point for my own project. This chapter so far has dwelt on techniques (i.e. loading and venting) that alter the resonance spectrum of the instrument to create imbalance, to perturb the stable system. The aim

---

very tools a player would normally use to alter intonation are hemmed-in by the constraints of the phenomenon.

in this final section is to establish a beginning for composing *with* this imbalance, in the knowledge that the point of the imbalance is to open the possibility for the instrument to suggest its own balances, its own stabilities. To rethink the clarinet (and all woodwind instruments) as landscapes of contingency.

It is important here not to read the term contingency as meaning something random, or as "anything goes". In any system, contingency is always in relation to the dominant, the stable, the predictable. In the normative performance traditions of most musics, contingency is trained out of instrumental technique. The point of technique is to make performance reliable and repeatable: arguably, driven in part by the need for capital to bring stable products to market, and the fungibility of musicians into the service industry. The many fields of musical improvisation tend to work against this, valuing, to varying extents, the contributions of the player, and the fecundity of responses in-the-moment. In post-Cagean experimental music, the contingency of musical instruments themselves has played a part in compositional strategies, often as a gesture of reduced control that allows in the lively unforeseen. In my work, I draw on Simondon partly because this allows for a contingency of growth and consequence. Not simply that unpredictable things happen, but that those unpredictable things then influence the ongoing unfolding of the system. In this way, contingency is not simply the throw-away, the excess that provides spectacle. Rather, contingency is history and structure, a form-giving potential. Contingency is the shape of a century-old oak tree where the main fork of the trunk can be traced back to the specific unfolding of a diffusion-reaction in the developing seed, or the light-level and position of the sun in the first few weeks of growth above the soil. Clarinet body resonances and performer technique are the site of contingency for the materially individuated clarinet.

Simondon's individuation is built on the biological process of growth, "biogenesis". In this way, the potentials inherent in the DNA of any given person or cat or jellyfish or daffodil allow for different expressions; that is, different individuals with different characteristics. The realisation of these potentials are constrained to certain sets—for example, human skin pigment varies across a diverse range of pinks and browns but is never green or blue—understood in biology as ontogenetic plasticity in the expression of traits from the general (genotype) to the specific individual (phenotype). Analogously, the potential in the resonances of any given fingering configuration tends to hew closely to a small set of dominant pitches for that fingering, but small variations and mixtures are definitely possible. In standard clarinet playing, all is "definitive states" with little contingency, but with unstable fingerings and non-standard tone-production mechanisms this plasticity can be brought to the fore. Compositionally, this allows for an approach where different strategies can be employed to drive the player to avoid the dominant possibilities and seek out more and more esoteric resonances and combinations. Central to these strategies are listening and repetition.

The techniques described above as the "dynamical clarinet" decenter stable and "formalistic" (De Assis 2017: 697) pitch-based understandings of the instrument through several strategies: (1) destabilising the instrument through loading and venting techniques that create unstable resonance columns, rich in potential multiplicities; (2) decoupling embodied techniques (breath, embouchure, etc.) from externally-imposed pitch structures by extending under/over-blowing as a continuum; and (3) establishing a relational understanding of the clarinet as multiple superimposed instruments with paths and linkages that connect them through embodied techniques and responsive engagement. The Garden of Forking Paths project takes up the compositional challenge of exploring this decentred network of potentials, establishing nodal points of compositional technique to amplify indeterminacy and contingentist affordances. Inherent in this approach is the paradox of the player-instrument assemblage wherein the player is simultaneously distanced from and connected to their instrument. The instrument is defamiliarized by decentring the historical formalism of tonal pitch, which is the constant ground of the player's technique. The compositional approaches use non-standard fingering configurations, and also extend this through loading and venting to engage in path-making and path-finding on the keyed-holed-interface without any reference to the familiar landmarks of known fingerings. Equally, by rendering embouchure as a continuum rather than a set of sedimented positions for accessing specific registers, the instrument becomes strange, and behaves with a new agency. However, all of this alienation is, to my mind at least, more than balanced by drawing the player further into the language of the clarinet by exploring it as a physical system continuously flowing anew in each moment: as a climber discovers the rock-face, as a surfer knows the ocean, as a plant knows earth and sky.

Clarinettists often describe the process of learning multiphonics as being a matter of familiarising with embouchures/setups that may be initially hard to reliably reproduce, but over time become learned, added to the repertoire of motor memory. This project moves that process from repertoire-time into performance-time. Rather than learning such positions across a lifetime of discovering and practicing (sedimenting) each new position, these compositions enact all that learning, negotiating, and accommodating, within the moment and unfolding structure of the performance. The process is made performative by the compositions' constantly individuating, flowing-through and skipping-across unpredictable cycles of unstable–metastable–stable through repetition of that space. The scores use instructions like simple computer programmes to create recursive loops, constrained by conditions of materiality and sensation. As the loop recurses through the embodied space it becomes familiar, and with it, technique becomes concrete only to again destabilise and replasticise as the score page turns. The compositions act to continuously deform technique, to make it plastic and responsive to the material moment. Compositions of The Garden of Forking Paths use repetition to allow contingent forms to emerge from exploring the same instabilities until something changes; the stable becomes unstable, or vice versa. The compositions are structured not in metric time or clock time, but a phenomenal time experienced as rates and degrees of change from "now" and "this", or reaching back to previous events that might act as beacons of return—whether or not they are ever actually reached. Composing becomes the structuring of potentials for ongoingness.

For me, the fundamental rethinking of the clarinet here is a centering of materiality, physicality, and sensation, and requiring Simondon's radical individuation to assert "the primacy of ontogenesis, a primacy of processes of becoming over the states of being through which they pass" (Massumi 2009: 37). It is both a rediscovery of the instrument's body and the player's body to find moments of structure. As the player explores through slight and continuous changes in body—lips-pushing, tongue-shaping, breath pushing and easing, throat tightening and loosening, fingertip flesh retreating impossibly gently off a metal ring to reveal the slenderest of far-less-than-half-hole gaps—there is a moment where the world resets, something is revealed, the sound changes, individuates. Massumi's description of Simondon's individuation captures this moment of invention from potential:

> The moment of invention is when the two sets of potentials click together, coupling into a single continuous system. A synergy clicks in. A new "regime of functioning" has suddenly leapt into existence. A "threshold" has been crossed, like a quantum leap to a qualitatively new plane of operation. … Invention is the bringing into present operation of *future* functions that potentialize the present for an energetic leap into the new. … Invention is less about cause than it is about self-conditioning emergence. (Massumi 2009: 39–40) … An inventivism that is not afraid of nature, and *its* creativity. (ibid: 38) [emphases in original]

References

Bardin, A. and Menegalle, G. (2015). Introduction to Simondon. *Radical Philosophy* 189: 15–16.

Backus, J. (1977). Multiphonic tones in the woodwind instruments. *The Journal of the Acoustical Society of America* 62: S1, S43.

Barad, K. (2007). *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham, NC: Duke University Press.

Benade, A. (1990/1976). *Fundamentals of Musical Acoustics*, 2nd ed. New York: Dover.

Bergeron, T. (1989). *Saxophone Multiphonics: A Scalar Model*. DMA dissertation, University of Oregon.

Caravan, R. (1974). *Extensions of Technique for Clarinet and Saxophone.* DMA dissertation, Eastman School of Music, University of Rochester, New York.

De Assis, P. (2017). Gilbert Simondon's "transduction" as radical immanence in performance. *Performance Philosophy* 3/3: 695–717.

Dick, R. (1975). *The Other Flute*. London: Oxford University Press.

Fletcher, N. and Rossing, T. (1998). *The Physics of Musical Instruments*. New York: Springer Verlag.

Gottfried, R. (2008). A more accurate notation for multiphonics using sideband ratios. URL: <www.ramagottfried.com/texts/rama_gottfried_multiphonics.pdf> [Accessed 20 October 2020]

Haraway, D. (2016). *Staying with the Trouble: Making Kin in the Chthulucene.* London: Duke University Press.

Ingold, T. (2011). *Being Alive: Essays on Movement, Knowledge and Description.* Abingdon: Routledge.

McLaughlin, S. (in press, 2021). On material indeterminacy. In E. Payne, M. Iddon, and P. Thomas (eds.), *Performing Indeterminacy*. Cambridge: Cambridge University Press.

Massumi, B. (2009). "Technical mentality" revisited: Brian Massumi on Gilbert Simondon. With Arne De Boever, Alex Murray and Jon Roffe. *Parrhesia*, 7: 36–45.

Mills, S. (2016). *Gilbert Simondon: Information, Technology and Media.* London: Rowman and Littlefield International.

Pickering, A. (1995). *The Mangle of Practice: Time, Agency, and Science*. London: University of Chicago Press.

Raasakka, M. (2010). Appendix 1: Harmonics. *Exploring the Clarinet*. Helsinki: Fennica Gehrman.

Roche, H. (2019). 9 Multiphonics that overblow from the second harmonic. URL: <https://heatherroche.net/2019/12/16/9-multiphonics-that-overblow-from-the-second-harmonic/> [Accessed 6 October 2020].

Sève, A. (1998). Le paradoxe de la clarinette. URL: <http://alain-seve.com/livre-intro.html> [Accessed 12 December 2020].

Sim, A. (2008). *303 Clarinet Fingerings and 276 Trills*. Buckingham: Queen's Temple Publications.

Wolfe, J. (n.d.). Clarinet acoustics: an introduction. URL: <https://newt.phys.unsw.edu.au/jw/clarinetacoustics.html#registerhol> [Accessed 21 October 2020].