CHAPTER TWO

Sounding Actions

According to Leonard Meyer, listening to music is like riding a bike (1973, 15–16). An experienced listener may safely ignore music theory and history, just as a cyclist may ignore the bicycle's engineering or physics. Riding a bicycle, of course, is a standard example of *know-how*.[1] That is to say, knowing how the bike works is not the same as knowing how to work it, and I cannot acquire this skill merely by reading a book or watching others ride. Instead I learn how to do it by doing it. I become a competent cyclist by pedaling and breaking, balancing or falling, again and again. Meyer's analogy usefully frames musical listening as habit and skill, as procedural rather than declarative knowledge. Yet there is also a significant difference between these activities: cycling is a form of human-machine interaction. And on this level, riding a bicycle seems less like listening than like playing a musical instrument.

A phenomenological description of cycling can help flesh out the comparison, and such a description might begin with the rider's body. On the bicycle my feet alternate, much as they do while I walk. Right and left, up and down, forward and backward. But cycling feet, unlike walking feet, never strike the ground. Instead they stay in contact with the pedals and move with them, while my hands do the same with the handlebars. As the handlebars swivel to the left or right, as I turn them with my hands, the bike tilts; my whole body leans. Steering, like riding in general, thus involves a play of balance and instability. In all of this, my body is integrated with the bicycle. Together we form a system. After all, the bike cannot ride itself without me.

In a sense, I am the bicycle's engine. My legs power the wheels, and when I pedal harder, they go faster. Still, there is a gap between my action and the bicycle's movement. It continues to roll after I have stopped pedaling. The bicycle, then, does not simply absorb my energy; it amplifies it. Of course, this process is mediated by the terrain, which is why cycling can reveal subtle declines and inclines in an otherwise familiar path. While coasting downhill with the wind in my face, riding faster than I can run, I need not pedal—even if I do, the pedals may spin freely. But while I am climbing uphill, those pedals feel stiff, and I become aware of my own heaviness and that of the bicycle. In both cases, I may shift gears, trying to maintain a satisfying resistance in the pedals, a sense of grip. Here I feel the bicycle but also the ground *through* the bicycle. I can feel, for example, when the path

1. This example is famously discussed by the scientist and philosopher Michael Polanyi (1958, 50), who is cited later in Meyer's essay.

changes from asphalt to gravel. Riding a bicycle, in the end, can be understood as a way of being in the world. As it alters my capacity for movement, the bicycle transforms my experience of space, of speed, and of my own body.

Both riding and playing instruments involve a complementarity of technology and technique. Both involve habit and withdrawal. But where the bicycle converts action into momentum, musical instruments convert action into sound. This chapter's first task is to theorize that conversion. How do various instruments transmit a player's actions? How do they transform a player's energy? Which sonic parameters reflect bodily action? Which reflect instrumental affordances? Though it starts by investigating sound production, this line of thinking ultimately reveals how a musical instrument, like a bicycle, can mediate experiences of the body itself.

Sounding Objects

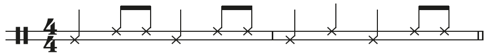
Strike a cowbell with a stick, and it rings. A momentary touch has initiated vibrations that stretch out in time and space. Of course, just as terrain affects the bicycle's momentum, performance environment can modify the bell's sound. For example, its ringing lasts longer in a reverberant concert hall. Nonetheless, the sound emanates from the cowbell itself, from this quivering piece of metal. And its sonic texture reflects that origin.

This relation between sound and source is central to ecological acoustics, a branch of Gibsonian psychology that considers how animals tune in to sonic aspects of their environments. People can *hear* the size of an object dropped into water and the hardness of a mallet hitting a pan; they can *hear* the difference between running upstairs and downstairs, between clapping with cupped or flat hands (Gaver 1988; Freed 1990; Repp 1987). For ecological acoustics, sounds are rich in information about the material forces that create them. Of course, such information does not determine perception. Attending to sources represents only one possible mode of listening, and the source of a given sound may be ambiguous, unfamiliar, or misidentified.[2] Still, this seems more likely with listeners who are distanced from a sound source than with players who can hear, touch, and see their instruments. Here different senses interact without fully converging. Insofar as sound indexes objects, hearing communicates with other sensory modalities. "I hear the hardness and the unevenness of the cobblestones in the sound of a car," writes Merleau-Ponty, "and we are right to speak of a 'soft,' 'dull,' or 'dry' sound" (2012, 239).

Or, with the cowbell, a metallic sound. In other words, the instrument's timbre can reveal aspects of its material. As William Gaver explains, "The damping of

2. Such misidentification may be fostered, though, by instruments that imitate other instruments—for example, the lute clavier (which I discuss in Chapter 5) or synthesizers (see De Souza, forthcoming). Chapter 6 examines modes of listening in greater detail. For a critique of deterministic applications of ecological acoustics (in discourse on electronic music), see Demers (2010, 36–37).

Figure 2.1 A standard cowbell pattern from salsa music (used with a 3:2 clave pattern). The bottom line corresponds to the mouth of the bell, the higher line to the body.



wood tends to be much greater than that of metal, which is why wood 'thunks' and metal 'rings'" (1993, 11).[3] Meanwhile, the bell's frequency reflects its size and shape—aspects of the instrument's configuration. Bigger bells, obviously, are pitched lower. And parts of a single cowbell afford distinct tones: the mouth sounds lower and fuller; the body, higher. This contrast is central to cowbell playing, for example, in salsa music (see Figure 2.1). In all of this, the sound of the instrument is predicated on its physical structure.

Yet ecological acoustics also considers the physical interactions that give rise to sound—in this case, how the cowbell is struck. Gaver specifically distinguishes between the sonic effects of interaction, material, and configuration (see Table 2.1) and describes how interaction principally affects dynamic and temporal features of the sound.[4] Tapped gently, the bell is quiet; whacked, it yelps. The loudness communicates the force of my attack. Note, too, the temporal difference between striking the bell and scraping it. And the timing of the attacks corresponds exactly to the sounding rhythm. From this perspective, sounds express ecological relationships. Recall the example of looking at a chair as I walk toward it (in Chapter 1), where visual invariants give information about the chair and changes give information about my movement. Likewise, in the cowbell pattern in Figure 2.1, sonic invariants reflect the instrument, while changes reveal the player's movement. This doubling—this intertwining of action and effect—underlies instrumentalists' auditory-motor coupling. Like a bicycle wheel, the instrument converts and amplifies an aspect of my action. As I make the bell speak, it makes my energy audible.

So hitting a cowbell may not be as simple as it seems. But how well does this percussive model generalize to other instruments? Consider an instrumental continuum proposed by Arnie Cox, which starts from a similar understanding of sound production.[5] Cox's continuum ranges from instruments with "no mediating device between the hands or mouth," to instruments played via implements (like mallets, bows, or keys), to electronic instruments, to mixers and computers (2011, 16).[6] By this point, musicians no longer provide the

3. Damping reduces the amplitude of oscillations (for example, through resistance, friction, or absorption of energy).
4. The stick's material again affects timbre: obviously, the attack of a wooden drumstick differs from that of a soft-tipped mallet.
5. For Cox, the relation between embodied action and sonic patterns fits into broader ideas about listening and mimetic motor imagery, already mentioned in Chapter 1.
6. Cox's continuum also extends to "music not performed primarily or solely by performers," such as birdsong or the "music" of a noisy factory (2011, 16). Since this category involves neither instruments nor players, I will set it aside here.

Table 2.1 Acoustic effects of source attributes (Gaver 1993, 11)

Source	**Effects on the sound wave**
Interaction	
Type	Amplitude function, spectrum
Force	Amplitude, bandwidth
Material	
Restoring force	Frequency
Density	Frequency
Damping	Amplitude functions; also frequency
Homogeneity	Complex effects on amplitude; also frequency
Configuration	
Shape	Frequency, spectral pattern
Size	Frequency, bandwidth
Resonating cavities	Spectral pattern
Support	Amplitude functions, frequency, spectrum

energy that produces sound. This is a continuum of increasing mediation, then, in which the player gradually loses touch with the site of sound production. On one side, action and sound correlate; on the other, they dissociate. This difference, however, cannot be reduced to an opposition between analog and digital instruments. Though digital technologies sometimes obscure a performer's movement, they may also amplify it. For example, the sensors in Tod Machover's "hyperbow" modify sonic output through gestural control.[7] Insofar as they afford continuous sonification of my movements, such technologies arguably give *more* information about the body than the pointed sound of a cowbell. And this is to say that the coupling of action and sound is not just natural but often engineered. On an electronic piano with touch-sensitive keys, the dynamics reflect the force with which I press the keys. A seventeenth-century harpsichord, by contrast, does not convey this aspect of my action. Whether it is played roughly or softly, the harpsichord's volume stays the same. Action and sound, then, do not necessarily diverge as instruments become more complex or as the number of mediators between my body and the vibrating medium increases.

Besides ranking different *degrees* of mediation, then, it is important to identify different *kinds* of mediation. The challenge is to tease apart various aspects of the sound, various functions of the instrument, to make sense of the diverse ways that musical instruments transform energy into sound. To that end, I turn to a distinctive scholar in the field of organology—whose work has surprising affinities with contemporary music theory.

7. For more on Machover's "hyperinstruments" see http://opera.media.mit.edu/projects/hyperinstruments.html.

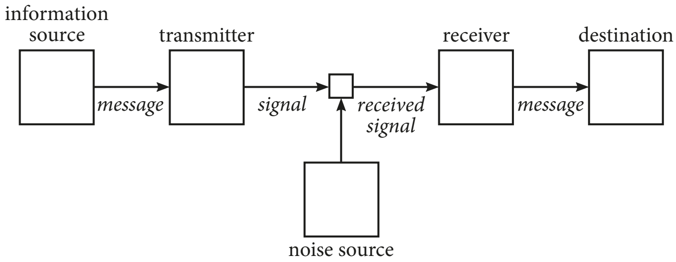
Instrumental Systems

Organology, the study of musical instruments, is inherently interdisciplinary, covering the science and engineering of instruments as well as their historical and cultural aspects. Modern organology typically classifies instruments in terms of the physics of sound production. For example, the widely used system of Erich von Hornbostel and Curt Sachs divides instruments into four categories: idiophones ("self-sounding" instruments, such as bells and woodblocks); membranophones (instruments with a stretched, vibrating membrane, such as drums and kazoos); chordophones (instruments with vibrating strings, such as guitars and pianos); and aerophones (instruments with vibrating air columns, such as flutes and pipe organs). This scheme aims to include "the whole range of ancient and modern, European and extra-European instruments"—and even instruments that have yet to be invented (Hornbostel and Sachs 1961, 7).[8] Its claims to universality are founded on the science of acoustics. Yet somewhat paradoxically, this foundation also reveals modern organology's historical origins in nineteenth-century Europe, where acoustical research enjoyed great prestige and influence.[9] By contrast, Herbert Heyde's *Grundlagen des natürlichen Systems der Musikinstrumente* (1975) develops an organology that is grounded in a scientific trend of the mid-twentieth century: cybernetics.[10]

Cybernetics is popularly associated with virtual reality (as in the terms "cyberspace," "cyberattack," and "cybersex") and human-technology hybrids (as in the "cyborg" or "cybernetic organism"). But the field of cybernetics, as developed in the 1940s and 1950s, investigates systems in general, whether technological, biological, psychological, or social. Cybernetics is concerned not with a system's material properties but with its abstract structure and behavior. As Ross Ashby puts it, "Cybernetics stands to the real machine—electronic, mechanical, neural, or economic—much as geometry stands to a real object" (1956, 2). For example, consider Claude Shannon's model of a general communication system, first published in 1948 (see Figure 2.2).[11] In this system, a message from some information source is fed into a transmitter. The transmitter encodes this message and passes it

8. In practice, electrical and electronic instruments pose problems for Hornbostel and Sachs's scheme (Kartomi 1990, 172–74). Also, some scholars have criticized organology for prioritizing a kind of scientism over social context (e.g., Bates 2012), in an argument that parallels attacks on music-theoretical formalism.
9. More broadly, nineteenth-century organology emerged at the intersections of acoustics, industrialized instrument-making, museum culture, and colonial encounters with non-Western music (see De Souza 2013, 7–14).
10. My discussion here responds only to the central section of Heyde's 1975 treatise, titled "Systemklasse" (Kartomi gives a brief overview of the book [1990, 189–90]). Moreover, cybernetic thinking does not characterize Heyde's later scholarship, which explores diverse topics in the history and science of musical instruments and organological methodology (e.g., Heyde 2001). He has also had a distinguished curatorial career, at the Metropolitan Museum of Art and other institutions, and received the Curt Sachs Award from the American Musical Instrument Society in 1991.
11. Incidentally, Shannon—one of the founders of information theory—collected musical instruments (Gallager 2001, 2683).

Figure 2.2 Claude Shannon's general communication system (after Shannon 1964, 34).



to a receiver, though not without interference from an external noise source. The receiver then decodes the signal, hopefully reproducing the original message. For Shannon's purposes, it does not matter whether the signal is sent via telephone wires, radio waves, or light beams. For a mathematical theory of communication, each element in the system may be treated as a "black box," reduced to a particular function. This generalizing move—a strategy of dematerialization—has provoked philosophical critiques of cybernetics (and the computationalist cognitive science that still bears its influence), though it also facilitates the application of cybernetic ideas in diverse domains.[12]

To approach musical instruments as cybernetic systems, Heyde starts by black-boxing instrumental components (1975, 22). The difference between Heyde's and Hornbostel and Sach's approach is striking. For Heyde, a string, a reed, and a drumhead belong to the same basic category (27). Each is a *transducer*, which takes energy from some *activator*—for example, a percussionist's hand or an organ's windchest—and changes it to sound. Every instrument couples an activator with a transducer. Instruments may optionally include further functional components, which are listed in Table 2.2, with Heyde's abbreviations and original German terms. The signal may pass through a *mediator* (like a violin bow) on its way to the transducer or through a *channel* at any stage. *Controllers, resonators,* and *couplers* may modify the signal. The remaining categories—*intermediate transducer, modulator*, and *amplifier*—are specific to electric and electronic instruments. After describing these categories (and subcategories within them), Heyde combines them in a general musical instrument system (*Ganzsystem der Musikinstrument*) (62). Any musical instrument, he claims, can be constructed as a subset of elements from the *Ganzsystem*. Like Shannon's communication system, a musical instrument system is a system of inputs and outputs, which transmits and transforms a signal.

For music theorists, Heyde's functional categories—arranged in a particular order, with some essential and some optional elements—may resemble a common

12. Hayles (1999) and Pickering (2009) offer critical histories of cybernetics, while Meyer (1967) combines music theory with information theory.

Table 2.2 Instrumental elements from Heyde (1975)

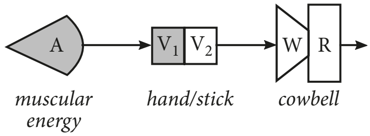
Label	German term	English term	Examples
A	*Anreger*	Activator	Muscles, lungs, bellows
V	*Vermittler*	Mediator	Violin bow, guitar pick, piano keys
W	*Wandler*	Transducer	Strings, membranes, reeds
ZW	*Zwischenwandler*	Intermediate transducer	Electric guitar pickup
M	*Modulator*	Modulator	Distortion pedal, electronic organ tone filter
Ampl	*Amplifikator*	Amplifier	Electric guitar amp, loudspeaker
R	*Resonator*	Resonator	Violin body, piano soundboard
K	*Kopulator*	Coupler	Flute tube
[circle]	*Kanal*	Channel	Violin bridge, flutist's throat
St	*Steuerelement*	Controller	Fingers, keys, switches

model of harmonic functions.[13] Just as a tonal phrase starts with tonic function (*T*) and leads to dominant function (*D*), instrumental sound production must start with some activating energy (*A*) and lead to a transducer (*W*, for *Wandler*); and just as predominant function (*P*) may intervene between *T* and *D*, a mediator (*V*, for *Vermittler*) may intervene between *A* and *W*. Of course, Heyde's ten instrumental functions are more numerous than the three harmonic functions, and they do not return to their starting point. Still, the comparison is useful. The interesting thing about a particular tonal phrase is not *that* it uses harmonic functions, but *how* it deploys them. Likewise, what is distinctive about an instrumental system is not just the functional components involved, but the structure of connections between components, what Heyde calls their "energetic, material, and informational couplings" (22).[14]

To analyze such structures in particular instruments, Heyde draws schematic circuit diagrams, diagrams of signal flow. For convenience, I will call these "Heyde diagrams." This graphic technique again recalls music-theoretical methods, since these schematics—like Schenkerian voice-leading graphs—are more than mere illustrations. Instead they supplement the written text, as a form of visual, symbolic argumentation. Heyde often presents the diagrams with minimal commentary, leaving it to his readers to investigate them independently. As a preliminary example, I offer a simple Heyde diagram for the cowbell in Figure 2.3. In this case, my body is the activator (*A*) and the bell itself is the transducer (*W*). These two functions, which appear in every Heyde diagram, have distinctive shapes: a "cone" for *A* and a trapezoid for *W*. Other components are represented as labeled rectangles. So one initial strategy for interpreting a Heyde diagram is to find the cone and follow the arrows to the trapezoid. In Figure 2.3, they are not immediately

13. For a critical interpretation of harmonic function, see Hyer (2011).
14. All translations from Heyde are mine.

Figure 2.3 Heyde diagram for cowbell sound production.



connected. Instead, mediators—the stick (V_2) in my hand (V_1)—direct energy to the bell. Note also that the bell itself performs a double function: it is a transducer but also a resonator. The distinction in shading is also meaningful here. In Heyde diagrams, human elements are shaded, while nonhuman elements have a blank background. Therefore, another strategy involves looking for boundaries between shaded and nonshaded zones. With the cowbell, that boundary comes between my hand and the stick. "Reading" such diagrams involves comparing interrelated levels, tracing various pathways through them—a practice that is not unfamiliar to music theorists. This type of analysis simply looks at the organization of an instrument rather than a piece of music.

Of course, most of Heyde's analyses are far more intricate than this preliminary example. Figure 2.4 reproduces and annotates his schematic for a Boehm flute. Boxes on the right side of the diagram represent parts of the instrument: sixteen keys (k_1–k_{16}) and a mouthpiece (W), joined to the cylinder that constitutes the flute's body (coupler, K). Fingers of both hands are connected to the keys, though the diagram indicates differences between the hands. Each right-hand finger operates multiple keys, while the right thumb is connected with none. Meanwhile, each finger of the left hand is associated with a single key, and the left thumb operates two. The activating energy here originates in the player's respiratory system. Air passes from the lungs (A), through the windpipe (a small circle, representing a channel), to the mouth (a switch symbol). Lips and mouthpiece together form the transducer (W)—and this symbol combines human (shaded) and nonhuman (nonshaded) elements. On the whole, then, this diagram shows the integration of flute and flutist. To paraphrase Heyde, the flute itself is only a subsystem (26).

Heyde diagrams present systems of linked nodes. In mathematical terms, these are a kind of graph.[15] A mathematical graph is a collection of points connected by lines. Formally a graph is defined by two sets: a set of vertices V (the points) and a set of edges E that pair vertices from V. For example, imagine a graph where $V = \{A, B, C\}$ and $E = \{\{A, B\}, \{B, C\}\}$. This simple graph would have three points and two lines. It might be drawn in various ways (as demonstrated in Figure 2.5), but such visual representations are, strictly speaking, not a constitutive feature of the graph.

15. Heyde's main source on cybernetics—a book by the neo-Marxist economist Oskar Lange (1965)—is effectively a mathematical treatise on transformations, networks, and graph theory.

Figure 2.4 Circuit diagram for a Boehm flute (adapted from Heyde 1975, 63).

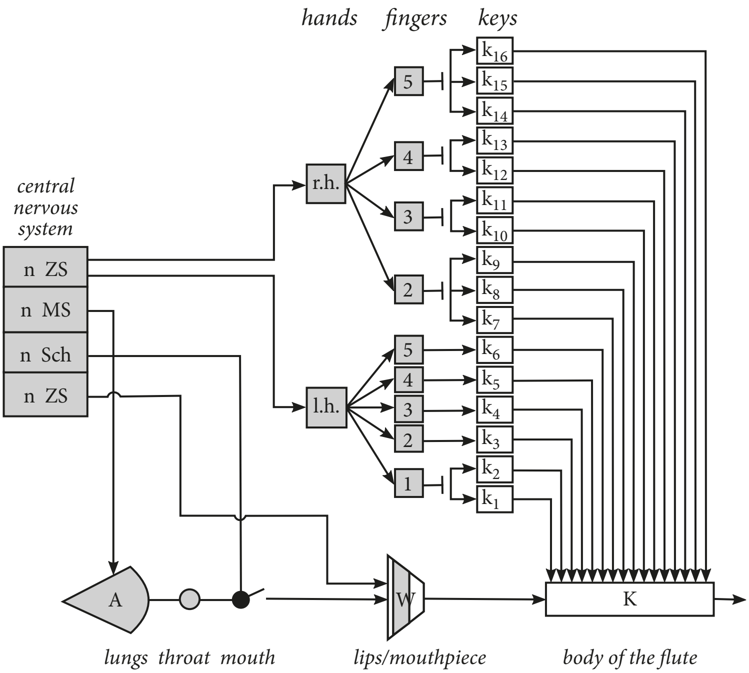
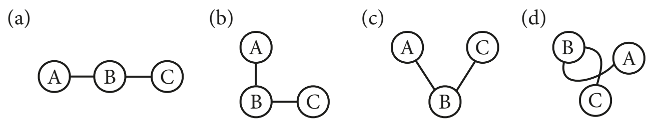


Figure 2.5 Four ways of drawing the same mathematical graph.



Graphs and networks are used in many diverse fields.[16] In music theory, they are central to transformational theory. Pioneered by David Lewin (1987), transformational theory uses mathematical group theory to model musical spaces, which may include but are not limited to pitch.[17] (For example, later chapters of this book will use transformational graphs and networks to explore various instrumental spaces.) The similarities go beyond the underlying mathematics to include conceptual attitudes: cybernetics is interested in systemic behavior, just as Lewin

16. Sporns (2010), for example, examines the importance of graph theory for neuroscience.
17. Rings discusses graph theory as part of a broader introduction to transformational theory (2011, 110–16). Readers who are familiar with transformational theory might note that whereas the “contents” of a transformation network are discrete elements from a mathematical group, Heyde’s schematics model a more or less continuous flow of energy. However, cybernetics often models continuous variables in terms of a “discrete machine,” using the framework of transformations, graphs, and networks as a more general conceptual resource (Ashby 1956, 28).

is interested in "musical behavior" (1986, 377). For example, Ashby's statement that cybernetics "does not ask 'what *is* this thing?' but '*what does it do*?'" (1956, 1, emphasis in original) resembles Lewin's "transformational attitude," which prioritizes subjective musical actions over objectified intervallic measurements.[18] More practically, this means that aspects of graph-theoretical thinking exercised in transformational theory—for example, ways of thinking about a graph's connectivity or directedness—can reveal interesting properties of particular Heyde diagrams.

From four source nodes representing the energy source, the graph in Figure 2.4 proceeds through a greater number of intermediate nodes before the arrows converge on a single "root" node, what Lewin calls an "output node" (1987, 207–8). Beyond that, its structure meets the conditions for an oriented digraph, employed in the study of tonal music by Steven Rings (2011, 111). Shared aspects of graphic structure suggest a surprising analogy here: just as independent voices in a tonal composition may start and finish in harmony, independent functional chains in flute playing unite in the final sound. Except for their final convergence at *K*, the two pathways in Figure 2.4 are indeed separate: there is an *activation pathway* involving the player's respiratory system and the mouthpiece, and a *control pathway* involving hands, fingers, and keys.

The energy that passes through this system originates in the performer's nervous system (*n*), represented by the four stacked, shaded rectangles on the left side of the diagram. Yet this energy is not undifferentiated. Heyde distinguishes between "energy-state control" (*Energiezustandssteuerung*, labeled *ZS*) and "energy-volume control" (*Energiemengensteuerung*, labeled *MS*). The former involves qualitative distinctions (for example, on or off), while the latter is quantitative (58).[19] This roughly corresponds to Shannon's distinction between discrete and continuous signals (1964, 34–35). Flute playing involves both forms of energy: the fingers set the keys' state (open or closed), corresponding to discrete pitch changes, while the breath involves variable amounts of energy (more or less), which create continuous fluctuations in volume.

In a way, Heyde's diagram shows relatively little about the flute's sound. Figure 2.4 does not specify what notes are produced by the various holes or key combinations on the flute. It represents a generalized Boehm flute rather than any particular flute or type of flute. For the moment, this abstraction, by usefully bracketing out pitch and rhythmic patterns, can focus attention on the process of sound production.

By bracketing off materiality, Heyde's organology, like cybernetics in general, posits a continuity between the mechanical and the organic. This theme is developed in Gregory Bateson's *Steps to an Ecology of Mind*:

> Some of these pathways happen to be located outside the physical individual, others inside; but the characteristics of the system are in no way dependent upon any

18. Here it seems worth mentioning that David Lewin, like Shannon, worked at Bell Laboratories, and Lewin is cited as a contributor to Jasia Reichardt's computer art exhibition *Cybernetic Serendipity* (1968, 7).
19. The opening and closing of the mouth corresponds to a third kind of control, what Heyde calls switch control (*Schaltsteuerung*, labeled *Sch*).

> boundary lines which we may superpose upon the communicational map. It is not communicationally meaningful to ask whether the blind man's stick or the scientist's microscope are "parts" of the man who uses them. Both stick and microscope are important pathways of communication and, as such, are parts of the network in which we are interested; but no boundary line—e.g., halfway up the stick—can be relevant in a description of the topology of this net. (1972, 251)[20]

If player and instrument are integrated in a "control circuit" (Heyde 1975, 25), aspects of technique can be distributed to the technology, and ultimately the player can be replaced by a nonhuman substitute.[21] For example, the human flutist can be replaced by a mechanical one, as in a celebrated eighteenth-century automaton created by Jacques de Vaucanson. One of Heyde's diagrams for the machine appears in Figure 2.6. Vaucanson's automaton plays the flute with mechanical fingers and a mechanical mouth, powered by a system of nine bellows. This translation from the human to the technical already implies an analysis of the human as part of a mechanical system, and indeed Vaucanson had studied the mechanics of human flute playing while designing his android (Riskin 2003, 613–16).[22] This means that not only the flute but also the flutist is a subsystem. The flutist who can be replaced by an android is already a cyborg.

Activation versus Control

And yet cybernetics misses something important. The flute-playing automaton might reproduce certain musical behaviors, but it cannot re-create the flutist's lived experience.[23] Heyde's distinctions, then, demand phenomenological interpretation. I am particularly interested in the distinction between activation and control, as represented in the two converging pathways in the flute system. Returning to my bicycle analogy, this resembles the gap between feet that pedal and hands that steer. In fact, the German word that Heyde uses, *Steuerung*, can be translated as either "control" or "steering."[24]

When I strike the cowbell, I use the stick to relay my energy to the instrument. But at the same time, I aim the stick at a particular part of the bell. Something

20. Focusing on the topology of the net is part of Bateson's cybernetic refusal of Cartesian dualism, which denies the distinction between the internal and external.

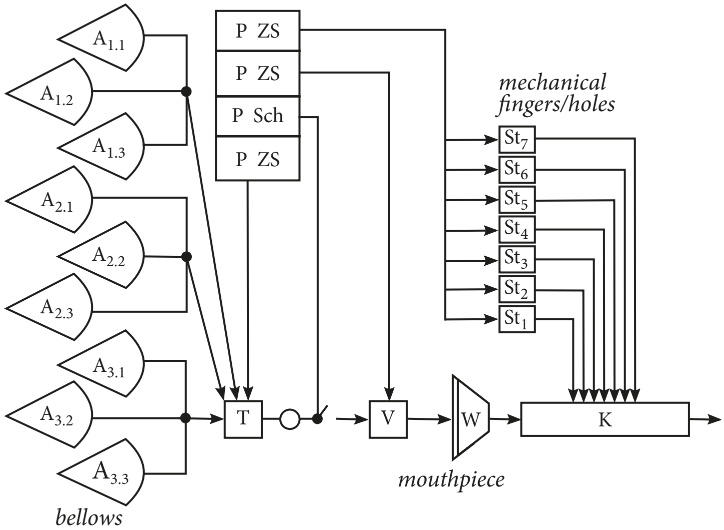
21. More generally, Bruno Latour theorizes both *associations* among human (H) and nonhuman (NH) actors and their mutual *substitutions*. "Of course, an H-H-H assembly looks like social relations," he writes, "while a NH-NH-NH portion looks like a mechanism or a machine, but the point is that they are always integrated into longer chains" (1991, 110).

22. For reflections on the historical and philosophical significance of musical automata, with their mechanical doubling of human performers, see Abbate (1999) and Yearsley (2002, ch. 5).

23. Here I echo Merleau-Ponty's ambivalence about cybernetics, which he discussed in lectures during the 1950s (2003, 165–66).

24. Note also that Norbert Wiener (1948) derived the term "cybernetics" from the Greek *kybernao*, meaning "to steer."

Figure 2.6 Circuit diagram for Vaucanson's flute-playing android (adapted from Heyde 1975, 61). In this diagram, the box labeled *T* represents a "junction" (*Verteiler*).



similar happens with the piano: my fingers make the strings sound (via the key-and-hammer mechanism), but they also select the keys. With such instruments, activation and control functions are mixed. These doubled actions might be compared to vector quantities in physics, which combine magnitude and direction. In this analogy, magnitude might correspond to the strength of the attack (communicated in dynamics), and direction to its placement (communicated in pitch). Even with these percussive instruments, though, the functions may diverge to some degree. Cowbell players often use a finger on the nonsticking hand to damp the bell, adding some control over timbre and duration. And though pianists' feet do not typically produce tones, they can control aspects of duration or dynamics through the pedals.[25] Thus, activation and control—though they can be combined and must be coordinated—are mutually irreducible.

These functions are distributed throughout the body in various ways. With the piano accordion, for example, my fingers control the keys, but pushing and pulling arms supply the energy—and thereby control the volume—via the bellows. Because of this single power source, all simultaneous notes on the accordion share the same dynamic, and it is not possible for the accordionist to bring out a line in a polyphonic texture by playing it more loudly. Whereas playing a note on the piano

25. With certain kinds of piano, the player's feet do produce sound: "pedal pianos" include a keyboard for the feet, and pianos with Janissary stops, popular in late-eighteenth- and early-nineteenth-century Vienna, have pedals that activate percussive effects inspired by Turkish military bands. Such pianos, however, are rare today.

is a percussive act, on the accordion I can hold a chord with my fingers and work the bellows to sustain it, "breathing" in and out with my arms. In this situation, I would be focused on activation and not control. As with other wind instruments, I may seem to be maintaining and manipulating a stream of energy rather than percussing an object.

With the violin, my right hand typically activates the sound, either through the bow or through plucking fingers, while my left hand stops the strings.[26] That is to say, my left hand cannot make the notes louder or longer. Usually both hands collaborate to produce pitches and rhythms, since the bow hand selects the string or strings to be played, and the left-hand fingers may rhythmically change notes during a sustained bow.[27] When I combine active bowing with an unchanging left hand, the violin has the feel of a percussion instrument. When long, sustained bows support rapid finger changes, I am more likely to feel as though I am manipulating a flow of energy. Either way, violin hands are more highly differentiated than piano hands or accordion hands, but also less independent.

The opposition of activation and control becomes clearer as functions are distributed between the player and the instrument. Figure 2.7 plots these possibilities on a semiotic square.[28] Each combination of terms creates a category, illustrated with musical instruments in Figure 2.7a and with vehicles in Figure 2.7b.

If the piano is like a bicycle, the pipe organ seems closer to a Harley-Davidson. When I play the organ, I guide the instrument without providing its energy. Slamming or caressing the keys does not affect the organ's volume, which is set by an expression pedal. The gentlest touch can create a thunderous tone. Though I have surely initiated this sound, the instrument's response may seem disproportionate. And the breath filling the pipes is not like my breath. This wind instrument has an endless air supply, sustaining tone indefinitely. The organ, then, combines two kinds of superhuman power—in its endurance and in its strength—and puts them at my disposal. These possibilities are, of course, central to the idiomatic technique of the pedal point. For example, consider the fourteen-measure pedal near the opening of J. S. Bach's Prelude and Fugue in A minor, BWV 543, an unstoppable sonic force grounding the passage work above (see Figure 2.8). The excess of instrumental energy in such gestures engineers a sense of transcendence, as powerful as any hidden orchestra or choir.[29]

The organ's nonhuman breath is thematized even more clearly in György Ligeti's *Volumina* (1962), a piece that explores overwhelming sustained clusters, shifting in color. At the end of the piece, Ligeti instructs the organist to switch off the organ blower. The organist continues to hold down the keys, and the sound

26. An exception to this is left-hand pizzicato, a technique found, for example, in the ninth variation from Niccolò Paganini's Caprice in A minor, op. 1, no. 24.
27. Note that the bow offers continuous control over rhythm and dynamics, but discrete control over pitch. And though the left hand can produce continuous pitch variation (in vibrato or glissandi), its fingers often seek to reproduce a discrete system of pitches.
28. The semiotic square is a tool for exploring structural oppositions, introduced by Greimas and Rastier (1968).
29. On the transcendental effects of concealed orchestras (a technique particularly associated with Richard Wagner), see Dolan (2013, 258–64) and Kane (2014, ch. 4).

Figure 2.7 Semiotic squares exploring activation and control (a) with musical instruments and (b) with vehicles. (Note that the handcar is a crank-powered railway vehicle, popularly associated with Wile E. Coyote.)

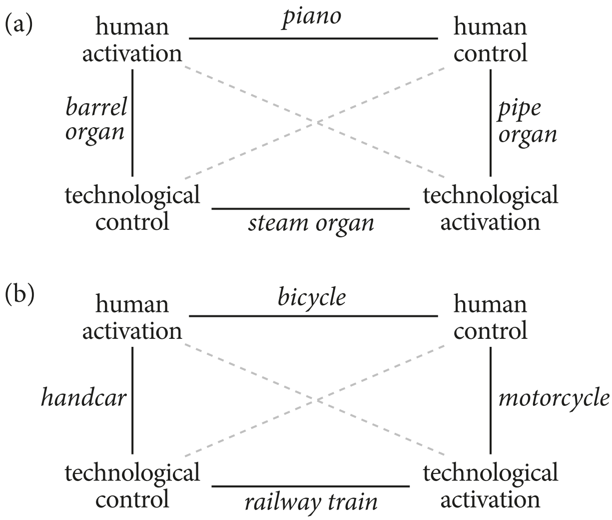


Figure 2.8 Johann Sebastian Bach, Prelude and Fugue in A minor, BWV 543, mm. 10–15. The pedal tone in the bass continues to m. 24.

gradually falters as the instrument runs out of air. Here Ligeti reveals the limit of a seemingly limitless energy source, highlighting an aspect of the organ that can easily be taken for granted.

So far, I have focused on human-controlled instruments. Yet as the square in Figure 2.7a shows, other possibilities are latent in the opposition of activation and control. Whereas the pipe organ combines mechanical energy with human control, the barrel organ inverts this pattern, combining human energy with mechanical control. With this inversion, however, some may question whether it is truly a musical instrument at all.

In the eighteenth and nineteenth centuries, the barrel organ was commonly used as a street instrument and in churches alongside "finger organs."[30] To play the instrument, an organ grinder turns a crank. This crank performs two functions, both hidden inside the instrument: it pumps the bellows, filling an air reservoir; and at the same time, it rotates a cylindrical barrel that is covered with a pattern of pins and staples. Each pin and staple opens a pipe to pressurized air from the reservoir, releasing a note in a programmed sequence. (Most barrels have multiple settings, to play multiple tunes.) Despite their popularity, barrel organs were widely denigrated (Hicks 2014). This is perhaps not only because of their contributions to urban noise or their populist repertoire, but also because of the organ grinder's ambiguous status as a musician. Some might view organ grinding as a purely mechanical activity, in which the player is automatized or instrumentalized. But playing the barrel organ does involve some skill. At the very least, the crank must be turned in the correct direction, since reversing it can damage the instrument. The organ grinder also controls the tempo, keeping it steady or varying it for expressive effect. And barrel organs, like pipe organs, often have multiple stops. Finally, many organ grinders obviously treat their work as a kind of performance. They often wear distinctive costumes, and gesture, dance, or sing along with the music. In this regard, they resemble the DJs studied by Mark Butler (2014, 95–105). Because their music-making obviously involves technological mediation, both organ grinders and DJs "perform performance." They work to convey personality and agency, to engage audiences, to emphasize "liveness." Despite the barrel organ's commonalties with musical automata and later recording technologies, then, it is still actively played.

Devices on the bottom edge of Figure 2.7a, in which both components are nonhuman, might seem even more liminal as instruments. Again, these are not necessarily digital or mechanical. A prime example here might be the aeolian harp, whose strings are activated by wind (an instrument that was discussed by Athanasius Kircher in the seventeenth century). But what of instruments that have to be *started* by a human? For example, a steam organ, which matches the pipe organ's mechanical power source with the barrel organ's programming? Is pressing an on/off button the minimal form of instrumental technique?

30. As a sample performance, I recommend the following YouTube video: https://youtu.be/ZClrDGnqd1Y. The earliest description of a barrel organ, however, appears in a ninth-century treatise by the Banū Mūsā brothers of Baghdad (Langwill and Ord-Hume 2001).

Of course, such questions are not uniquely related to musical instruments. Instead they engage broader issues in the history of technology, which are discussed in Jean Baudrillard's *The System of Objects*. For Baudrillard, older objects rely on human energy and ability, and are therefore shaped for the body. A hammer's handle—or a piano's keyboard—presupposes a strong, skilled hand. Yet, he continues, as technical objects have become more intricate, the related gestures have grown simpler, ultimately creating technologies that are more complex than the techniques required to operate them: "Buttons, levers, handles, pedals (even nothing at all—as when one passes in front of a photo-electric cell) have … replaced pressure, percussion, impact or balance achieved by means of the body, the intensity and distribution of force, and the abilities of the hand" (1996, 51). Buttons, in this account, demand neither effort nor dexterity. They reflect an increasingly abstract—but also increasingly free—connection between body and object.

The Monome 64, developed by Brian Crabtree and Kelli Cain, presents an 8 × 8 grid of identical square buttons.[31] The buttons can light up, but they are not pressure-sensitive and have no predetermined function. In Crabtree's words, "The wonderful thing about this device is that it doesn't do anything really" (quoted in Emsley 2011, 43). A button takes on an effect—triggering a sound, an audiovisual clip, or an action in a video game—only when the Monome is coupled with some software. The Monome, then, combines strict constraints with endless customizability. On this level, its buttons seem to embody the kind of abstraction theorized by Baudrillard.

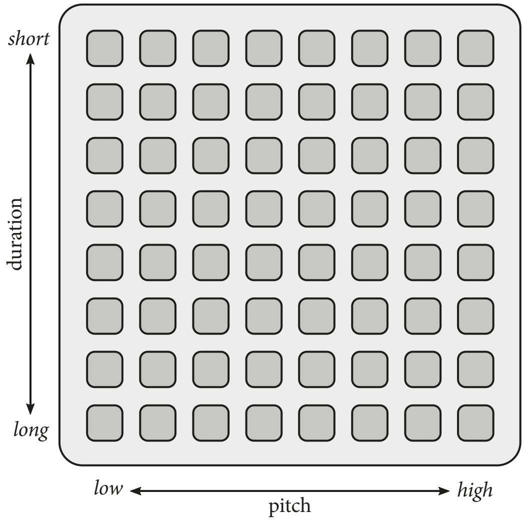
But although the Monome could easily be set up as a kind of jukebox (where the press of a button would play a complete prerecorded track), it is more commonly used to realize various musical spaces and processes. For example, Crabtree's "flin" app (released under his performance name, "tehn") creates an instrument with repeating notes.[32] Figure 2.9 models this arrangement. Each column of buttons corresponds to a single pitch, with lower pitches on the left and higher ones on the right. Similarly, the rows map onto duration, with higher rows producing shorter notes. Pushing a button, then, produces a looping note with a unique pitch and length. Each note is visually represented by a line of lights descending along the column like slow-motion raindrops. It is possible to press a few buttons and let the app run indefinitely, to watch and listen as the notes go in and out of phase. Here the Monome, like an automaton or aeolian harp, seems to play out a nonhuman musical process. Activation and control both come from the instrument itself. Yet it is also possible to intervene, to thicken or thin the texture, to change the notes or durations, to reintroduce human control.

Butler describes this mode of performance as "playing with something that runs" (2014, 106–8). His description draws on his performing experience with both classical music and electronic dance music (EDM). While playing piano, he must remain constantly involved in sound production. But while DJing, he can

31. The Monome grid is available in larger sizes too. Butler examines these controllers in the context of various technologies used in electronic dance music (2014, 87–89). As he notes, the Monome is not associated with any particular software. Instead, it works with a variety of programs, including open-source software developed by a community of users (88).

32. For a demonstration, see https://vimeo.com/418349.

Figure 2.9 Diagram showing pitch and duration layout for “flin” on a Monome 64.



step back and listen to a process unfold, taking time to plan his next move. “By shifting some of the responsibility for sound production from the performer to the machine,” Butler concludes, “EDM technologies cultivate the emergence of a distinctively interpretive role *during performance*” (108, emphasis in original). A related difference between pianists and DJs might involve the habits of auditory-motor integration discussed in the preceding chapter. Though DJs might develop similar multisensory connections, they would likely be more flexible than those found in classical pianists. (Again, the abstraction of the Monome may engender a certain kind of freedom.)

In terms of the semiotic square in Figure 2.7a, “playing with something that runs” might involve an alternation between human and technical control. It is also possible to combine human and technical energy sources. With the electric guitar, for example, I directly activate the vibrating string—but the unplugged guitar responds in a whisper. When I connect it to an amplifier and hit the on switch, it feels like a different instrument. Simply tapping the string now produces a bold tone, especially if I have added a distortion pedal to this musical circuit. The force with which I pluck the string is still reflected in the guitar’s volume, but magnified, supercharged. Here, again, technical and phenomenological aspects of instrumental sound production mingle with cultural values. For better or worse, the way that the electric guitar “empowers” its player is bound up with the ways that the instrument has been gendered in popular culture.[33] Instead of being pinned in a single place on the square, then, this

33. Robert Walser (1993) and Steve Waksman (1999) have both examined such aspects of electric guitar culture.

instrument offers experiences of sound production that are defined by dynamic tensions among the square's elements.

From Feedback to Incorporation

Sound production—conceived as the transmission and transformation of energy—might seem like a one-way process. After all, the arrows in the Heyde diagrams presented earlier always point forward. Yet for a performer, sound also provides a kind of *feedback*. Indeed, Heyde's first circuit diagram includes a feedback loop—an arrow that wraps around, going back to the nervous system through the ear (1975, 24). Such a loop, in a sense, is implicit in all later diagrams.[34] (That said, certain self-powering instruments let the player experiment with auditory feedback. Here I am particularly thinking of an electric guitar technique known as "volume swells," in which the guitarist activates the string with the volume off, then fades in with the volume knob or a volume pedal.)[35] Auditory feedback helps guide specific aspects of performance, particularly with continuous parameters. For example, auditory feedback is essential for intonation on bowed string instruments. When experienced cellists shift along the fingerboard but do not bow the string, their left hand drifts away from the correct position (Chen et al. 2013). In this case, the control pathway cannot properly function without the activation pathway. Despite years of practice, the cellist's motor performance depends on auditory feedback.[36]

Instrumental performance involves other forms of sensory feedback too. Many performers can *see* their hands on the instrument, and this visual information can be useful when they are executing certain actions (such as large leaps). Visual feedback is often important for beginners as well: for example, an experiment with beginning piano students indicated that "covering the hands of the learners so that they could not see the keyboard was to some extent detrimental to learning" (Brown 1934, 527). Still, not all instruments offer an equal amount of visual feedback. A flute can be seen only peripherally, and a diatonic harmonica is completely hidden in the player's hands.

Tactile feedback is also essential, particularly for timing.[37] Aschersleben, Gehrke, and Prinz (2001) found that anesthetizing participants' hands did not affect their ability to tap as rapidly as possible or to air-tap along with a beat. But their ability to synchronize key taps with a beat was significantly compromised.

34. Feedback is a central concept for cybernetics, because of its role in a system's self-regulation.
35. Eddie Van Halen's solo electric guitar track "Cathedral" from the 1982 album *Diver Down* uses volume swells to imitate an organ. For an analysis of "Cathedral," see De Souza (2016b).
36. Similarly, Hafke-Dys, Preis, and Trojan (2016) investigated the effects of altered pitch feedback on violinists' motor performance. In this experiment, violinists accurately compensated for the pitch shift, even when they could not consciously perceive the alteration.
37. Tactile feedback can be distinguished from kinesthetic or proprioceptive feedback, which involves bodily movement but not touch.

From this perspective, the hand is not just an output device. Rather, information flows in both directions. The hand touches and is touched.[38] Unlike its auditory or visual counterparts, tactile feedback allows for experiences of resistance. I feel my finger make contact with the piano key, and I feel it when the key hits bottom. This feedback, again, is important for temporal regulation. As the tempo becomes faster, pianists lift their fingers higher and strike the keys more forcefully, and increasing tactile information in this way improves temporal accuracy (Palmer and Dalla Bella 2004; Goebl and Palmer 2008). Clarinetists do the same, even though their fingers do not affect note onset or volume (Palmer et al. 2009). Tactile feedback can also pass through a mediating implement. For example, I feel the cowbell at the tip of the drumstick, not at the position of my hand.[39]

The key point here is that playing an instrument mixes multiple streams of feedback, involving what Merleau-Ponty calls "exchanges" between the visible, audible, and tangible (1968, 143). This multisensory integration underlies the action-effect binding discussed in Chapter 1, shaping players' perception and production of sound. Beyond that, though, such feedback may modulate the experience of one's own body.

Here, while recalling the Husserlian distinction between *Körper* and *Leib*, it is useful to invoke a related distinction *within* the category of the lived body—a distinction between body image and body schema.[40] The body image involves a conscious awareness of my body, the lived body as intentional object.[41] The body schema, on the other hand, is preconscious and supports automatic movements. Though the body schema involves reflexes and so on, note that this does *not* correspond to a distinction between a natural and a cultural body. Learned skills and habits register at both levels.

Though these two aspects of the body are typically mixed in lived experience, they may come apart. The classic example of a gap between body image and body schema is the phantom limb. Since the patient is aware that the limb

38. Both Husserl ([1929] 1960, 97) and Merleau-Ponty (2012, 94–95; 1968, 147–48) discuss this doubling in terms of one hand touching the other. For Merleau-Ponty, touching and being touched intertwine without fully coinciding. "When I press my two hands together," he writes, "it is not a question of two sensations that I could feel together, as when we perceive two objects juxtaposed, but rather of an ambiguous organization where the two hands can alternate between the functions of 'touching' and 'touched' " (2012, 95). This non-coincidence, to use a harmonic analogy, might be compared to a pivot chord: it functions in two keys, but I can hear it only in one key at a time. Wiskus (2013) approaches Merleau-Ponty's philosophy of non-coincidence via music, painting, and literature.

39. Yamamoto and Kitazawa (2001) use a temporal discrimination task with crossed hands to show that stimuli are not located at the position of the hand, but sensed at the drumstick's *tip*.

40. Merleau-Ponty discusses the body schema (*schema corporel*) in *The Phenomenology of Perception*, drawing on earlier work in neurology by Henry Head (1920). For terminological issues here, see Gallagher (1986) and Sheets-Johnstone (2005). In a review of neurophysiological and psychological research on the body schema, Graziano and Botvinick (2002) emphasize its reliance on interconnected sensory and motor areas in the parietal lobe and premotor cortex.

41. In phenomenology, intentionality refers to the "aboutness" or "directedness" of experience. That is, every experience is an experience of *something* (and that something is an "intentional object").

has been amputated, it is no longer part of the patient's body image. Yet it persists in the body schema.[42] As Merleau-Ponty writes, "To have a phantom limb is to remain open to all of the actions of which the arm alone is capable and to stay within the practical field that one had prior to the mutilation" (2012, 84).

More rarely, the body schema itself may be impaired, resulting in a loss of the sense of bodily position and movement (Cole and Paillard 1995). One patient suffering from this unusual neuropathy can verbally explain where her body has been touched or locate it on a diagram but, without visual information, cannot point to the place on her body. She knows the touch in terms of body image but not body schema (254). Such patients are able to move their bodies but must consciously regulate every move. Sitting on a chair, holding an egg without crushing it, gesturing while talking—these usually automatic actions, for them, require effort and attention. As another patient puts it, he cannot walk and daydream at the same time (262). Besides revealing the everyday reliance on automatic bodily habits, such cases demonstrate the nonidentity of body image and body schema.

Exploiting this gap can produce fascinating phenomena, such as the "rubber hand illusion" (Botvinick and Cohen 1998). While a participant is seated at a table, one of the participant's hands is hidden by a screen, and a rubber hand is put in its place. An experimenter uses paintbrushes to stroke the hidden real hand and the visible rubber hand at the same time. Through this coordination of visual and tactile feedback, participants come to feel that the rubber hand is part of their own body.[43] Surprisingly, such an illusion can take place in the absence of the artificial hand: if the experimenter systematically strokes an empty space while stroking the unseen hand, the participants may come to feel that they possess an invisible hand (Guterstam, Gentile, and Ehrsson 2013). And if the experimenter then "stabs" the invisible hand with a kitchen knife, this evokes increased skin conductance (a common physiological measure of arousal). The body schema, then, can incorporate even empty space, inducing a kind of phantom-limb experience.[44]

In a similar study, the experimenter gently taps a participant's hand with a small hammer (Senna et al. 2014). The participant wears headphones, in which the sound of the hammer against the participant's skin is gradually replaced by the sound of a hammer tapping marble. If the marble sounds are temporally coordinated with the felt taps, uncanny effects appear after five minutes: the hand begins to feel numb, stiff, heavy, and hard. It feels like a marble hand. In the rubber hand illusion, I come to feel what I see; in the marble hand

42. Phantom limbs are consistent with the phantasmal voices and other simulations discussed in perceptual symbol systems theory (see Chapter 1). Indeed, some commentators argue that phantom limbs provide strong evidence consistent with Barsalou's theory (Edelman and Breen 1999).
43. Neuroimaging research suggests that the premotor cortex is involved in the multisensory integration that produces a sense of bodily ownership (Ehrsson, Spence, and Passingham 2004).
44. It is, however, considerably more difficult to induce the sense of ownership with an object that does not resemble a hand, such as a wooden stick (Tsakiris and Haggard 2005). This suggests that such illusions require a mix of bottom-up and top-down processes.

illusion, what I hear. Multisensory feedback reconstructs the sense of one's own body.

These experiments indicate conditions under which the body may incorporate tools or other objects. Navigating with a stick alters the body schema because it provides multisensory feedback. When blind people regularly use a cane, their sense of personal space expands. Tactile and auditory awareness focuses on the area at the tip of the cane. For experts, the perceptual changes are more or less permanent, but they can be temporarily induced in sighted people who have been trained to use a cane (Serino et al. 2007). Like riding a bicycle, navigating with a stick involves practical know-how, which, despite its conscious aspects, must be grounded at the level of the body schema. "If I want to become habituated to a cane," writes Merleau-Ponty, "I try it out, I touch some objects and, after some time, I have it 'in hand'" (2012, 144).[45]

All of this, finally, can help explain why musicians sometimes claim that an instrument feels like part of the body. I would hypothesize that such experiences are more common when multisensory feedback is maximized—that is, when an instrument's sound reflects multiple aspects of the player's action and when tactile and visual feedback match the auditory image. In other words, the illusion of instrumental incorporation seems more likely with human activation and control than with a self-propelling instrument like the Monome. Mediators like bows or drumsticks (which, like the cane, can be felt *through*) might also enhance the illusion. Gibson's distinction between "detached objects" (which I can pick up and move) and "attached objects" (which are fixed) seems relevant too (1979, 133). But this might simply be because detached instruments like the violin or flute stay in continuous contact with the body.

Some players actively seek a sense of bodily extension. The trumpet virtuoso Jens Lindemann, for example, tries to foster it in his students. "It's a lifelong pursuit trying to get to that point of comfort," he says, "but when you do arrive there you realize that you're just taking a piece of metal and you're blowing through it. It's that simple and that complicated at the same time."[46] Of course, the feeling of incorporation, like any form of withdrawal, will be fleeting. The experience, surely, differs in notable ways from the experience of having a rubber hand, and musicians may not intend that their statements about such experiences be taken literally. Still, these psychological and philosophical perspectives suggest that playing an instrument can change the experience of one's own body, that in music as in other domains the boundaries of the lived body can be reshaped by technics.

45. Another study by colleagues of Serino showed that tool use can alter perceptions of one's own body. After participants used a mechanical grabbing arm, their reaching behavior changed, and their estimates of their own arm length slightly increased. Briefly put, they acted as though they had longer arms (Cardinali et al. 2009).

46. See http://www.artistshousemusic.org/videos/your+instrument+as+an+extension+of+your+body.

Conclusions

Instrumental sound production, generally speaking, involves a certain reciprocity: actions are converted into sounds, and sounds give feedback about actions. As such, player and instrument together can be understood as a system that generates and transforms musical energy. Yet because this coupling is realized in countless ways, analyses of particular instruments must untangle the contributions of bodily technique and instrumental technology, considering their phenomenological and sonic effects.

Physical traces, of course, are also audible in voices. This is central to Roland Barthes's reflections on the "grain of the voice." The "grain" refers not just to vocal timbre but to contributions of "the tongue, the glottis, the teeth, the mucous membranes, the nose" (1977, 183). "The 'grain,'" Barthes explains, "is the body in the voice as it sings, the hand as it writes, the limb as it performs" (188).[47] Additionally, the sense of vocal ownership, like bodily ownership in general, can be influenced by multisensory feedback. In one notable experiment, the participants spoke words while simultaneously hearing a voice in headphones say the same words (Zheng et al. 2011). With this congruence between auditory information and vocal motor activity, the participants came to feel that the other voice was their own.[48] This "rubber voice" illusion is possible because vocal production is both felt and heard.

As my voice resounds outside of me, it may sometimes be experienced as a kind of object. Whereas instrumental incorporation brings a tool into the body schema, this objectification exteriorizes voice, projecting corporeal activity outward. But a voice is a slippery thing.[49] After all, my voice originates *inside* my body. I can neither grasp nor see it, and I hear it "from within" (Merleau-Ponty 1968, 144; Vitale 2008). In the end, then, this chapter differentiates instrumental and vocal sound production. Singing is like running rather than cycling. Though running and singing are undeniably technical, they do not require a prosthesis—something set before me—that transforms my energy and grounds my actions.[50] Variations in vocal tension, for example, are not tethered to tangible spots in the world. I can point to a middle C on the piano or violin but not in my voice. Voices, that is, do not spatialize pitch in the same way that many instruments do.

47. Barthes explicitly extends the grain to instrumental music, with a brief discussion of keyboard performance (1977, 188–89).
48. I would hypothesize that the voice can incorporate other sounds as well. This could be tested by modifying the procedure of Zheng et al. (2011), replacing spoken words with sung notes and the stranger's voice with instrumental tones.
49. For a discussion of the ambiguities surrounding voice—and a concise overview of the extensive scholarly literature on voice—see Feldman (2015). I discuss voice-instrument relations in De Souza 2014.
50. Of course, this presumes a "naked" voice. Various musical technologies—from kazoos to vocoders to microphones—*do* transform vocal energy. These instruments, it might be said, are "played" with the voice.

The question of instrumental space, however, goes beyond sound production. Heyde diagrams may outline an interface's topology, but they do not show how it affords specific sets of pitches. Yet this will be crucial for understanding how instrumental organization relates to tonal organization and how an instrumental space, with its boundaries and privileged zones, might affect players' creative actions.