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Abstract
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Toward a New Organology:
Instruments of Music and Science

by John Tresch* and Emily I. Dolan†

ABSTRACT

The Renaissance genre of organological treatises inventoried the forms and functions of musical instruments. This article proposes an update and expansion of the organological tradition, examining the discourses and practices surrounding both musical and scientific instruments. Drawing on examples from many periods and genres, we aim to capture instruments' diverse ways of life. To that end we propose and describe a comparative "ethics of instruments": an analysis of instruments' material configurations, social and institutional locations, degrees of freedom, and teleologies. This perspective makes it possible to trace the intersecting and at times divergent histories of science and music: their shared material practices, aesthetic commitments, and attitudes toward technology, as well as their impact on understandings of human agency and the order of nature.

LOOKING BACKWARD FROM THE DIGITAL CONVERGENCE

This *Osiris* collection is part of a widespread and growing scholarly fascination for the connections between the sciences and the arts. While much of this work has focused on the visual arts, our editors have happily shifted their attention to sounds and music. The previous articles in the volume demonstrate through their diversity the rich paths of inquiry that are opened up by this focus, leading us from Young's correlations of light and sound and Helmholtz's experiments with *Klangfarbe* to the twentieth-century military-industrial university and to questions surrounding tuning, temperament, and the standardization of pitch. Our contribution picks up a theme that has loomed large over this collection in many guises; namely, that of instruments and instrumentality. In what follows, we attempt to think systematically about the very idea of the instrument and the central roles instruments play in science and music. The variable uses and interpretations of instruments are now firmly established as central topics in the history of science, and musicology appears to be heading in a similar direction, slowly overcoming the artificial divide that was created in the early twentieth century between the study of music (musicology) and the study of instruments (organology).[1] Our goal is to suggest ways of lacing together these par-

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[1] According to organologist Wesley M. Oler, the term "organology" dates from Nicholas Bessaraboff's seminal work, *Ancient European Musical Instruments* (Cambridge, Mass., 1941): in a clear

allel developments, by focusing on the variable uses and modes of action of instruments in both fields.

One factor that has encouraged the growing interest in the technical infrastructures of music and science and the connections between them is the recognition that for the past two decades, just about anyone working in a field that requires communication—including scientists, visual artists, and musicians—must make use of a new set of tools: those provided by the computer. Media scholars, pundits, and precocious preteens have helped us recognize the fecundity of computers as both instruments and imaginative resources. While digital technology makes both artistic and scientific productions possible, it also provides metaphors and methods (networks and codes, bits of information crunched and transformed) that move across the alleged great divide between the two cultures. Further, the computer merges two aspects of technical instrumentation that are often seen as diametrically opposed. On one hand the computer appears as an autonomous, purely rational calculating machine, processing bits of abstracted information with inhuman rigor, speed, and accuracy. On the other, as digital media insert themselves into more and more aspects of our work, leisure, and social lives, computers seem to unite themselves fluidly and corporeally with human users, becoming emphatically "extensions of ourselves," as Marshall McLuhan characterized all media. Even at the level of hardware design, the "form factor" of digital technology makes these devices appear as supple, sticky interfaces, forming an ergonomic skin connecting us to the world.

The sudden ubiquity of this diversified but integrated interface explains some of the urgency with which both the history of science and music studies are turning to studies of instruments: What is new, many ask, and what was ever thus, in humans' engagement with instruments? The current proliferation of digital technologies has also altered our perspective on those objects that the digital replaces or imitates. All of the new forms of musical production and consumption—iTunes, iPods, YouTube, and digital editing software—reconfigure the relationship between machines, instruments, and their traditional functions. Take for example Apple's popular Logic Pro program, which allows its users the ability to control every aspect of producing music, "from the first note to the final master."[2] Musicians can record, edit, and mix music, with access to thousands of sampled instruments, pedal boards, filters, amplifiers, loops, and spaces (i.e., acoustic profiles of particular locations, from cathedrals to wine cellars). Its encyclopedic functionality blurs the distinction between physical instruments and already synthesized material.

But Logic Pro doesn't only imitate the sounds of specific instruments. Apple promises that the user can "play models of the Hammond B3 organ, the Hohner Clavinet D6, and the Fender Rhodes, Wurlitzer, and Hohner electric pianos—with all the character and quirks of the originals."[3] Its interface seeks to reproduce the physical

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reference to Michael Praetorius's term *organographia* (see n. 6 below), Bessaraboff used the term to refer to "the scientific and engineering aspects of musical instruments." See Oler, "Definition of Organology," *Galpin Society Journal* 23 (1970): 170–4. The Galpin Society, dedicated to the study of instruments and still flourishing today, was founded in the same decade that Bessaraboff's study was published. On the history of scientific instruments, see Albert van Helden and Thomas L. Hankins, eds., *Instruments*, vol. 9 of *Osiris*, 2nd ser. (1994).

[2] "Logic Pro," Apple, http://www.apple.com/logicpro/top-features/ (accessed 13 Apr. 2013).

[3] Ibid. Logic Pro is one of a number of forms of software displaying this kind of "technostalgia." The new Peter Vogel CMI iPad app, for example, allows the user to recreate the experience of working with the original Fairlight Computer Musical Instrument sampler, right down to setting the fail rate of the

characteristics of mixers, pedal boards, and drum machines: the user can still turn virtual knobs and dials and press virtual buttons—a feature that is surely as much a concession to nostalgia as it is a useful way of bridging the gap between physical device and software. Logic Pro transforms its embedded objects. Within this world, a guitar is no longer a physical prosthesis for the performer, liberating forms of artistic expression while simultaneously circumscribing the performer's range through its technical specifications and limitations. In Logic Pro, the instrument becomes synonymous with its effects; it becomes, as it were, purely aesthetic—a particular texture, a timbre, as well as a cultural resonance that can be conjured up with a few clicks. We see and hear the original instrument, as a material object, in new ways. The metamorphosis from physical objects to digital plug-ins draws attention to the historicity of Logic Pro's new and old instruments; instruments have life histories, and multifaceted and changeable personalities.

Similar observations about the re-mediation of scientific instruments are inescapable. In contemporary sciences, computer-based models and simulations of processes at subatomic, molecular, physiological, cerebral, geological, or astrophysical scales illustrate a growing power of digital imitation; unprecedently massive new data sets are compiled and subjected to automatic analysis; new fields, such as bioinformatics, come into being thanks to comparatively easy access to vast computing power.[4] Ultimately, every aspect of laboratory life—from experiment, visualization, and data storage and processing to communication among lab members, including scheduling, collaboration, and publishing—has been transformed by the presence of computers. The tools that made up the previous infrastructure and material backdrop of the lab have been replicated, subtly altered, and amalgamated into layered and networked instruments of instruments.

The fact that the arts and the sciences now share so many aspects of their technical infrastructure results in isomorphic logics, shared working strategies, and common imaginaries between them. It has also made it easier to recognize earlier convergences between the fields and to find in them compelling anticipations of our own moment, leading to reflection on the ways in which instruments have facilitated intersections between the fine arts and the sciences, as well as the different ways they have been understood in relation to humans. While we could build on a growing body of work that juxtaposes the sciences with the visual arts, the instruments of science and music in many ways form a more intriguing pair.[5] While visual art objects are records of past work with paint, pencil, canvas, or stone, for there to be music at all, the instrument has to be currently at work (at least, that was the case until the arrival

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floppy-disk reader. On the historical performance and re-creation of electroacoustic technologies, see Joseph Auner, "Wanted Dead and Alive: Historical Performance Practice and Electro-acoustic Music from Abbey Road to IRCAM," in *Communicating about Music: A Festschrift for Jane Bernstein*, ed. Roberta Marvin and Craig Monson (Rochester, forthcoming).

[4] In addition to the explosion of writings seen since 2012 on "big data" (e.g., Steve Lohr, "The Age of Big Data," Sunday Review, *New York Times*, 11 Feb. 2012), see the influential statements of Jim Gray in *The Fourth Paradigm: Data-Intensive Scientific Discovery*, ed. Tony Hey, Stewart Tansley, and Kristen Tolle (Redmond, Wash., 2009); for critical discussion, see Chris Kelty, Lilly Irani, and Nick Seaver, eds., *Crowds and Clouds*, issue no. 2 of *Limn*, http://limn.it/issue/02/ (accessed 29 Sept. 2012).

[5] For studies of correlations between visual and acoustic media in nineteenth- and twentieth-century arts and sciences, see Mara Mills and John Tresch, eds., *Audio/Visual*, vol. 43 of *Grey Room* (Spring 2011).

of automatic recording). Further, from Pythagoras onward there has been a supposition of unity between science and music. At the same time, there is reason to think of these fields as complementary: musical instruments express the inner states of the composer or the performer, moving outward from the mind to the world, while scientific instruments bring external states of the world into the consciousness of observers, moving from the world to the mind. Given the current acute sense of the ways in which new instruments of communication and representation are changing our modes of thinking, arguing, and perceiving, the time is ripe for trying to get historical perspective on these changes, by means of a comparative study of instruments in different fields.

Part of our inspiration comes from Renaissance texts such as Sebastian Virdung's *Musica getutscht und ausgezogen* (1511) and Michael Praetorius's *Syntagma Musicum* (1618).[6] These organographical treatises catalogued a wide range of musical instruments in a systematic fashion, organizing them into families according to their construction and use. The same classifying impulse lies behind the present article, but our focus is broader in that we also include scientific instruments and attend to historical differences. We are aiming at an analysis—and perhaps a new taxonomy—of the ways people (primarily in the West) have understood instruments' action and their bearing on humans. In what follows, we will sketch some of the features that might define a systematic study of the natures, uses, degrees of agency, and ends of instruments in different fields and at different times: a new organology.

If all we were after were a historical inventory of instruments, the first task would be to assemble materials. In the case of music, we would consider taxonomies, organologies, orchestration treatises, collection guides, and museum inventories. For science, we would turn to similar instrumental compendia: laboratory manuals, *cabinets de physique*, and kits for calibrating instruments and setting up laboratories, as well as the correspondence exchanged between different observatories and labs about coordinating and standardizing equipment. But we are aiming at something more. We want to think about instruments as actors or tools with variable ranges of activity, with changing constructions and definitions, and with different locations in both technical and social formations. We want to ask, What aspects of instruments have been variable (or have been seen to be), and what were the consequences of that variation? What were the larger arrangements of technology, social roles, and elements of the natural world (breath, electricity, the air, metal, biological specimens) into which particular instruments were woven? How was their action understood: Were they neutral vehicles for human intention or external nature, or did they transmute or modify the impulses they carried along? What larger projects, goals, or conceptions of either the arts or sciences, or both, did they help to articulate?

To get at these differences and similarities, we will take a lesson from a prominent focus of attention in recent history of science: the different ethical ideals at work in scientific research. In parallel with studies of "epistemic virtues" and the ethics of the knowing subject, we propose as a thought experiment—one that will surely provide more questions than answers—a comparative study of the ethics of instruments.

[6] Virdung's work is the earliest printed treatise on instruments; for more information, see Beth Bullard's translation, *Musica getutscht: A Treatise on Musical Instruments* (Cambridge, 1993). The term "organology" derives in part from the second volume of Praetorius's *Syntagma Musicum*, entitled *De Organographia*, which was devoted to descriptions of musical instruments.

THE ETHICS OF INSTRUMENTS

Instruments are integrated in diverse ways with human activities; they also influence understandings of human conduct and freedom. In thinking about instruments as having an ethical dimension, our approach dovetails with recent attempts to characterize moments in the history of science by the epistemic virtues that have guided the pursuit of natural knowledge.[7] Ethics, in such works, turns out to be important for epistemology: knowledge appears not merely as a set of ideas or even practices, but as a form of life, with distinct ideals, moral codes, activities, and understandings of the self.[8] This broadened conception of ethics as a form of life resonates with comparative studies and histories of the self (e.g., by Marcel Mauss, or more recently by Charles Taylor and Jerrold Siegel).[9] It also takes inspiration from the later works of Michel Foucault.

In the works published toward the end of his life, Foucault reframed ethics as essentially concerned with the self's relation to the self. He saw this relation as consisting of four dimensions: an *ethical substance*, or the part of the self understood to be addressed by ethics, including the relevant domains of activity (economic exchange, food, sex, vocation, etc.); a *mode of subjection,* or the relation of the subject to explicit codes of conduct, rules, and obligations; the *ethical work,* or the activities through which the subject is constituted; and finally the *telos,* or the ends toward which this activity is directed.[10] Foucault laid particular emphasis on the idea of ethics as an aestheticization of existence: in his interpretation of texts from ancient Greece and the Hellenistic period, he saw the care of the self (in ascetic practices such as self-examination and journal keeping) as guided by the ideal of creating a beautiful life. In late interviews and occasional pieces he presented more recent ethical constellations, such as Baudelaire's theorization of dandyism in the 1860s and attempts to refashion friendship as the basis of gay life in the 1970s, as modern updates of the view of ethics as an aesthetics of existence. Ethics was less concerned with moral proscriptions than the practices and ideals through which one constituted oneself as a free subject and as a work of art.[11]

Yet Foucault's conception of the ethical telos of ancient philosophy has been criticized as too narrow. According to Pierre Hadot, his focus on aesthetics obscured the

[7] See, e.g., Peter Galison and Lorraine Daston, *Objectivity* (New York, 2007); Matthew Jones, *The Good Life in the Scientific Revolution* (Chicago, 2004).

[8] For Daston and Galison, ethical conduct is "a way of being in the world, for a group or individuals" (*Objectivity* [cit. n. 7], 40).

[9] Mauss, "A Category of the Human Mind: The Notion of Person; The Notion of Self," in *The Category of the Person: Anthropology, Philosophy, History*, ed. Michael Carrithers, Steven Collins, and Steven Lukes (Cambridge, 1985), 1–25; Taylor, *Sources of the Self: The Making of the Modern Identity* (Cambridge, Mass., 1989); Siegel, *The Idea of the Self: Thought and Experience in Western Europe since the Seventeenth Century* (Cambridge, 2005).

[10] Michel Foucault, *The History of Sexuality*, vol. 2, *The Use of Pleasure*, trans. Robert Hurley (New York, 1990).

[11] "The idea of morality as obedience to a code of rules is now disappearing, has already disappeared. And to this absence of morality corresponds, must correspond, the search for an aesthetics of existence." Michel Foucault, "An Aesthetics of Existence," in *Politics, Philosophy, Culture: Interviews and Other Writings*, ed. Lawrence Kritzman (New York, 1988), 49; see also his interview entitled "Friendship as a Way of Life" in *Foucault Live: Interviews, 1961–1984* (New York, 1996), 203–7, and his essay "What Is Enlightenment?" in *The Foucault Reader*, ed. Paul Rabinow (New York, 1984), 32–50. For a more recent, hilarious theorization of dandyism, see Lord Breaulove Swells Whimsy, *The Affected Provincial's Companion*, vol. 1 (New York, 2006).

Epicurean and Stoic understanding of ascetic practices as means of situating oneself in the universal order and accessing a "cosmic consciousness" as embodied in the figure of the sage.[12] While Foucault reframed ethics as a transhistorical dandyism, Platonic and Stoic self-fashioning aimed instead at placing the individual into harmony with the order of the universe—which is not necessarily the same thing. For ancient philosophy, ethics was closely tied to cosmology.[13] We might further add the obvious point that in all standard accounts, ethics bears upon one's conduct toward family, friends, allies, and enemies; it involves the self's relation not only to the self, but to others. Following Hadot, then, we need to expand Foucault's conception of ethics to include further contexts of ethical conceptualization and activity: the self's relation to the cosmos or nature, and the self's relation to other selves.

Modified in these ways, Foucault's later works provide a useful, multidimensional framework for comparing ethical systems. But what if we were to go one step further, and apply this framework not only to humans—in their capacities as active and knowing subjects—but to the instruments with which humans engage as they create knowledge and other cultural products? What if we shift our gaze from the relations between self and self, and self and nature (as traditionally explored in ethics and epistemology), to consider the variable relations between selves and instruments, tools, and machines? What then comes to light is a framework for studying the historical variations in an ethics of instruments—a history that parallels and intersects that of ethics and of the knowing subject. A comparative ethics of scientific instruments could also be juxtaposed with the relations of selves and instruments found in fields other than science; for instance, in music.

Such a project requires us to reckon with the many different ways in which instruments, tools, and machines have been understood. We need to expand our view beyond the standard notion of the tool as utilitarian and passive, and beyond the ideal of the machine as embodying inhuman precision and standardization—the uniform, predictable, sharp-edged ideal underlying "mechanical objectivity."[14] Across time and in different contexts, instruments and machines have changed in their material configuration, their mode of activity, their relations to other objects and people, and their aims. These changes have had consequences for how humans understand themselves. Upending the view of technical progress as increasing domination over nature, for instance, Thoreau famously said, "We do not ride on the railroad, it rides upon us." Are tools understood as granting us mastery, or are they seen as reducing us to cogs in what Lewis Mumford called the "megamachine"?[15] Or, alternatively, are they seen as establishing a complicated balance, weaving us into the fabric of a second nature? The answers to these questions will depend on the era, the instrument, and the field.

To give precision and reach to the notion of an ethics of instruments, we propose the following analytical categories. Though they are inspired by the four axes that

[12] See Hadot, *Philosophy as a Way of Life* (Oxford, 1995); discussion in Arnold Davidson, "Ethics as Ascetics: Foucault, the History of Ethics, and Ancient Thought," in *The Cambridge Companion to Foucault*, 2nd ed., ed. Gary Gutting (Cambridge, 2005): 123–48.

[13] In *The Good Life* (cit. n. 7) Matthew Jones shows how this was also the case for early modern natural philosophers.

[14] See Daston and Galison, *Objectivity* (cit. n. 7).

[15] Henry David Thoreau, *Walden; or, Life in the Woods* (1854), in *A Week on the Concord and Merrimack Rivers, Walden, The Maine Woods, Cape Cod* (New York, 1985), 396; Mumford, *Technics and Human Development*, vol. 1 of *The Myth of the Machine* (New York, 1971).

made up Foucault's analysis of the self's relation to the self, we have tweaked and tuned them in order to apply them to instruments. An instrument's ethics, we suggest, may be analyzed according to the following categories:

1. The *material disposition* of the instrument: the nature and configuration of its elements, and the materials and parts that make it up. Also, and perhaps most important, this disposition is defined by which parts are seen as necessary to make the object an instrument of a certain type, and which may be varied to alter its specific action. (This corresponds to what Foucault called the ethical substance, that part of the self made an object for moral reflection.)
2. The instrument's *mode of mediation*: whether its action is considered to be autonomous or passive, modifying or transparent, hidden or visible (corresponding to Foucault's ethical activity, the work conducted to make oneself a subject of ethics).
3. The *map of mediations* of which the instrument is a part. Such maps, joining together a number of distinct elements, may be rather complex: in music they include air, sound, composers, players, other instruments, and listeners, as well as orchestration treatises and rules of composition; in the sciences they include the phenomena being investigated, the observer or experimenter, and other elements in the experimental system, as well as rules of method, laboratory protocols, scientific institutions, and patterns of moving between observation and generalization. (This category relates to what Foucault calls the mode of subjection, or the subject's relation to rules or obligations.)
4. The *telos* of an instrument's activity, or its ends (Foucault uses the same term to describe the goal of ethical work). What is the nature of the enterprise within which the instrument is deployed; what are its social contexts and uses, and the social, economic, and political relations they express, reinforce, or perhaps modify? At the level of telos we might also want to bring in broader conceptions of the goals attributed to instruments (much as Hadot suggested in his critique of Foucault mentioned above): not the instrument's relation to itself but its relation to its users and those exposed to its products, as well as its impact on the entire collective. Furthermore, we might consider the relationship an instrument is seen to entertain with the natural order, with the cosmos as a whole.

This approach means that we will be applying concepts to nonhuman objects that are usually attributed to humans. Exploring the different forms and degrees of agency attributed to instruments suggests that the qualities of sentience, activity, and intention might not always belong only to humans but also to objects often classed as inanimate, including machines and instruments.[16] Yet, as Bruno Latour has argued, an ambivalence between human agency and the agency of machines is a common theme in considerations of technological inventions of all kinds: "The label 'inhuman' applied to techniques simply overlooks translation mechanisms and the many choices that exist for figuring or defiguring, personifying or abstracting, embodying or disem-

[16] Such a conception builds on recent interrogations of the liveliness of matter; e.g., Bill Brown, "Thing Theory," *Critical Inquiry* 28, no. 1 (2001): 1–22; Jane Bennett, *Vibrant Matter: A Political Ecology of Things* (Durham, N.C., 2010); Manuel De Landa, *A Thousand Years of Non-linear History* (Cambridge, Mass., 2000).

bodying actors. When we say that [technologies] are ‘mere automatisms,’ we project as much as when we say they are ‘loving creatures’; the only difference is that the latter is an anthropomorphism and the former a technomorphism.”[17] If instruments are frequently accused of making humans act mechanically, why should we not take seriously instruments’ oft-noted lifelike capacities?

The following pages elaborate and illustrate the four categories we have proposed as steps toward a new taxonomy—a classificatory scheme for ordering the long series of scientific instruments and the long series of musical instruments. Our examples are drawn from medieval and early modern settings as well as from the Enlightenment, romanticism, industrial modernity, and postmodernity. If this kaleidoscopic view is somewhat disorienting, so much the better: we hope that our instrument-focused approach to the conjunctions of music and science will allow readers to see (and hear) things from a new angle. At the very least, the organological framework we develop should be a provocation to thinking about distinct aspects of the instruments at work in both of these fields. In addition, we see this analysis as providing the grounds for the construction of parallel historical series for scientific and musical instruments, and, eventually, for a comparison between them. In other words, we hope to address such questions as, What do the ways in which people built, used, and thought about musical instruments in a given period tell us about the scientific instruments in the same period, and vice versa? Where do historically specific ways of thinking about scientific instruments converge with those for musical instruments? More broadly, what do those interactions tell us about the changing relationships between science and the arts, or about the changing relationships among humans, nature, and technology? While answers to such questions must lie in the future, throughout the following discussion of the four categories that make up an ethics of instruments—material disposition, mode of mediation, map of mediations, and telos—certain suggestions along these lines should be apparent, and more will be sketched in the conclusion.

MATERIAL DISPOSITION: MICROSCOPE, TELESCOPE, KEYBOARD

In examining the material disposition of an instrument, we ask, What is the instrument made of, and how are its components arranged? Its configuration of parts might change, even as the same name is applied to it. Take for example the microscope. From early designs even preceding Robert Hooke’s, microscopes involved lenses and mirrors. Their aim was to enlarge visual access to the very small, and they worked by deviating rays of light to magnify the image of an object as it reached the eye. In contrast, the electron microscope, which first appeared in the 1930s, projects a ray of electrons through a thin slice of the object being observed; these are then captured on photographic film. Because electrons have much shorter wavelengths than the photons of visible light, they grasp much finer textures. Similarly, the scanning electron microscope sends a highly focused beam across an object’s surface; as the electrons’ energy is transformed, it is recorded as the basis for a reconstruction of spatial features. Though these instruments share a name, the electron microscope—

[17] Latour, “Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts,” in *Shaping Technology, Building Society: Studies in Sociotechnical Change*, ed. Wiebe Bijker and John Law (Cambridge, Mass., 1992), 225–58, on 241.

as well as nanotechnology's defining instrument, the scanning tunneling microscope (or STM)—are constructed and function according to principles quite distinct from the lenses and luminous optics of the instruments originally called "microscopes."[18]

The telescope has undergone a comparable evolution.[19] From Roger Bacon's thirteenth-century explorations with "seeing stones" to Newton's reflecting telescope, the optics of natural light and vision were put to work in making very distant objects close, again by bending rays of light to expand the visible image. Improvements in lenses and increases in scale continued apace. In the twentieth century, new telescopes appeared that no longer used visible light as their medium. In 1931, radio waves emitted from the Milky Way were detected, and the radio telescope, with its characteristic disk pointed at the sky, became a defining feature of the modern observatory. Infrared rays are tracked by telescopes usually placed on mountaintops, and ultraviolet and gamma-ray telescopes are attached to satellites; some, like the Hubble, travel untethered through space. Although these instruments often result in visual images—colored and shaded according to the conventions of romantic landscape painting—these are post hoc constructions, visual mappings of the vast quantities of data generated by automatic sweeps of the sky, given a wide berth for selection and modification by their creators.[20]

Beyond their smaller scale, cost, energy inputs, and technical complexity, the underlying physical processes at work in the early microscope and telescope were completely different from those of their more recent successors: direct ocular observation versus automatic collection of electromagnetic radiation or capture of electron beams and their subsequent statistical analysis.[21] Microscopes and telescopes each offer an example of an instrument that undergoes profound transformations at the level of its material disposition—what it is made of, which aspects of the external world it engages with, how it functions materially—while remaining an instrument of the same kind.

In contrast, the material disposition of an instrument, or some key part of it, might remain basically constant over time, while the instrument, as it combines with other elements, becomes an entirely new tool used for different functions. The keyboard, for instance, offers an example of an enduring interface that has been attached to a wide range of technical apparatuses. The basic concept—an instrument controlled by a series of levers operated by fingertip pressure—is ancient. Within music, it has been part of the organ, harpsichord, clavichord, piano, and synthesizer, as well as shorter-lived inventions whose names are largely forgotten today. Medieval key-

[18] Jutta Schickore, *The Microscope and the Eye: A History of Reflections, 1740–1870* (Chicago, 2007); William Croft, *Under the Microscope: A Brief History of Microscopy* (Singapore, 2006); Cyrus Mody, *Instrumental Community: Probe Microscopy and the Path to Nanotechnology* (Cambridge, Mass., 2011).

[19] Henry King, *The History of the Telescope* (New York, 2011); Alison Morrison-Low, Sven Dupré, Stephen Johnston, and Giorgio Strano, eds., *From Earth-Bound to Satellite: Telescope, Skills and Networks* (Leiden, 2011).

[20] Elizabeth Kessler, *Picturing the Cosmos: Hubble Space Telescope Images and the Astronomical Sublime* (Minneapolis, 2012).

[21] In this respect, astronomy resembles the many other fields of science that have been transformed in the last decade and a half by their heavy reliance on automatic data collection and algorithmic data mining. See the discussion in the case of meteorology and more generally in Paul Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, Mass., 2011), and, more programmatically, in Hey, Tansley, and Tolle, *Fourth Paradigm* (cit. n. 4).

boards were, by and large, diatonic—that is, they had seven or eight pitches to an octave. The keyboard layout we know today in the modern piano, which comprises the twelve pitches of the chromatic scale, has existed since the fifteenth century.

Throughout history, various inventors have attempted to alter the traditional design, creating keyboards that move away from C major as the center, use additional keys that allow microtonal music, or are arranged in different configurations understood to allow for easier transposition or more ergonomic playing, but such efforts have remained experimental. The interface of the keyboard has structured in profound ways inventors' conceptions of new instruments and machines. The late eighteenth and early nineteenth centuries witnessed a flurry of activity aimed at inventing an instrument to capture an idealized "voice of nature"—a sweet, nuanced sound that would resemble human singing. Benjamin Franklin's glass harmonica (invented in 1761), a series of tuned glass bowls, played directly with moistened fingertips and threaded on a rod that the performer turned with a foot treadle, spurred this activity. The shortcomings of Franklin's mechanism—its inability to play rapid passages, sluggish response time, and nasty habit of making performers sick—inspired later inventors to combine the glass harmonica's ethereal tones with a more manageable interface. And that interface was, for most inventors, the standard keyboard: from Ernst Florens Friedrich Chladni's clavicylinder to the harmonichord of Johann Gottfried and Johann Friedrich Kaufmann, instruments of this period contained wildly differing mechanisms, all accessed by means of a keyboard. It was precisely the presence of the keyboard that made these instruments accessible to the public imagination.[22] Indeed, for an instrument inventor *not* to use a keyboard for a complex new instrument required some justification. Synthesizer pioneer Don Buchla, for example, rejected using a keyboard interface for his 1970 Music Box. "A keyboard is dictatorial," he argued. "When you've got a black and white keyboard there it's hard to play anything but keyboard music. And when there's not a black and white keyboard you get into the knobs and the wires and the interconnections and the timbres, and you get involved in many other aspects of the music, and it's a far more experimental way."[23] Trevor Pinch and Frank Trocco have shown how Robert Moog also initially resisted fitting his synthesizer with a keyboard until his collaborator Herb Deutsch convinced him to reconsider.[24]

But the keyboard helped to structure nonmusical instruments as well. In the early 1840s, the interface of the first machines for mechanically composing and distributing type was directly modeled on the piano keyboard; many of these devices were called "pianotypes." While this name made the musical roots of these devices explicit, the lever systems of many early typewriters did not look much like pianos, arranging keys in circular, spherical, and semicircular layouts. However, Samuel W. Francis based the action of his typewriter on that of the mid-nineteenth-century piano, and the Remington typewriter followed this lead. Even when the keyboard did

[22] On these inventions, see Emily I. Dolan, "E. T. A. Hoffmann and the Ethereal Technologies of 'Nature Music,'" *Eighteenth-Century Music* 5, no. 1 (2008): 7–26; Myles Jackson discusses the scientific context of some of these instruments in *Harmonious Triads: Physicians, Musicians, and Instrument Makers in Nineteenth-Century Germany* (Cambridge, Mass., 2006).

[23] Quoted in Trevor Pinch and Frank Trocco, *Analog Days: The Invention and Impact of the Moog Synthesizer* (Cambridge, Mass., 2002), 44.

[24] Ibid., 59.

not directly replicate the layout of a piano, skills could transfer from one domain to the other. In a late nineteenth-century history of the still rapidly developing machine, P. G. Hubert reported that

> the most elaborate typewriter ever constructed was that made a few months ago for little Joseph Hofmann, the boy pianist. . . . After less than two hours' practice, he wrote letters in several languages to friends in different parts of the world, who might not yet know what a typewriter is.[25]

Hofmann (1876–1957) was a child prodigy and one of the great pianists of the twentieth century; his purported ability to master typing in two hours testified to his general virtuosic dexterity. But the connection existed even for nonvirtuosi. Those skilled at the piano were better positioned to develop dexterity on writing machines, a fact with important social consequences: because the pianotype was less physically taxing than previous techniques of text composition, women could take over the craft at lower wages—replacing skilled male workers.[26] Likewise, Kittler has argued that the resemblance between piano and typewriter enabled women to transition from leisured domestic music making into paid secretarial work. This connection was clear to those witnessing the birth of the female clerk in the nineteenth century. Writing in 1895, two German economists remarked:

> Today, the *typist* has evolved into a kind of type: she is generally very high in demand and is the ruling queen in this domain not only in America but in Germany as well. It may come as a surprise to find a practical use for what has become a veritable plague across the country, namely piano lessons for young girls: the resultant dexterity is very useful for the operation of the typewriter. Rapid typing on it can be achieved only through the dexterous use of *all fingers*.[27]

The history of the keyboard helps raise a series of questions about instruments' material dispositions. What conditions are necessary for a new instrument to succeed? How are the material elements of one instrument reterritorialized onto new instruments? Likewise, the history of the microscope and telescope lead us to ask, What must stay the same for an instrument to remain the same kind of thing over time? How much variation is possible within a single family of instruments, and along which dimensions? At what point have the underlying mechanics and mode of function shifted such that we can no longer call the instrument by the same name as its precursors?

MODE OF MEDIATION: WHO'S PLAYING WHOM?

In January 2011, the renowned guitarist and composer Marc Ribot held a monthlong residency at Le Poisson Rouge in Manhattan. Those in attendance watched Ribot transition from charismatic virtuoso, single-handedly commanding attention, to thoughtful ensemble member, self-effacingly attuned to the needs of the group. Even

[25] Hubert, "The Typewriter; Its Growth and Uses," *North American Review* 146, no. 379 (1888) [unpaginated].

[26] François Jarrige, "Le mauvais genre de la machine," *Revue d'histoire moderne et contemporaine* 54 (2007): 193–221.

[27] Quoted in Friedrich A. Kittler, *Gramophone, Film, Typewriter*, trans. Geoffrey Winthrop-Young and Michael Wutz (Stanford, Calif., 1999): 194–5.

more striking, however, was his relationship to his instrument: at times the guitar appeared as a seamless extension of his body, utterly under his control; other times, he made the separation between performer and instrument clear, cradling the guitar in his arms like he was embracing another being. He often seemed to meet the instrument halfway, grappling with the guitar's own agency. This fluidity calls attention to the different modes of mediation that may be at work when a user interacts with an instrument. Any history of instruments must also account for their changing forms of agency and visibility. Do we understand a given instrument within a given context as passive and obedient to the hand of the user, or does it appear as active, occasionally beyond the user's complete control? How much does the instrument control the user, and vice versa?

Different historical periods and cultural settings have offered starkly contrasting answers to these questions. In the case of the late Enlightenment and the romantic era, intriguing connections between the agency of musical and scientific instruments abounded. The early part of the career of the famed astronomer William Herschel (1738–1822) was spent amid not telescopes but musical instruments. Born in Hanover, he worked as an oboist and violinist for the Hanover Guards. Abandoning the post and its harsh conditions, he performed and composed music outside London, eventually securing a position as organist at the Octagon Chapel in Bath in 1766. He composed over two dozen symphonies, numerous concertos, chamber music, music for keyboard, and vocal works. A versatile instrumentalist, in January 1787 he performed concertos in Bath for both oboe and violin and a sonata for the harpsichord. The autograph manuscripts of his oboe concertos contain an unusual number of nuanced and precise performance indications.

During the 1770s, Herschel's astronomical interests grew. He began to construct his own telescopes and stands, meticulously grinding his own lenses; he collaborated with his sister Caroline, whose childhood encounter with typhus left her unmarriageable in the eyes of her parents.[28] In 1781, Herschel realized that the sidereal object he had thought was perhaps a comet was actually a planet. He named the planet Georgium Sidus; only later (perhaps unfortunately) was it renamed Uranus. After this discovery, King George awarded Herschel an annual salary, allowing him to concentrate entirely on astronomy. Yet elements of his musical career persisted. Connecting his musical and astronomical endeavors was the notion of practice. In a letter from 1782, Herschel wrote:

> I do not suppose there are many persons who could ever find a star with my power of 6,450, much less keep it, if they found it. Seeing is in some respects an art, which must be learnt. To make a person see with such a power is nearly the same as if I were asked to make him play one of Handel's fugues on the organ. Many a night have I been practising to see, and it would be strange if one did not acquire a certain dexterity by such constant practice.[29]

Looking through a telescope required the same kind of dedicated practice as the performance of fugues at a keyboard. Herschel's skill in constructing instruments rein-

[28] See Michael Hoskin, *Discoverers of the Universe: William and Caroline Herschel* (Princeton, N.J., 2011).

[29] Herschel to Dr. William Watson, 7 Jan. 1782, in Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and His Sister Caroline Herschel* (New York, 1933), 99–101, on 101.

forced his artful seeing. His telescopes were neither wholly active nor entirely passive instruments: each new and larger telescope that he constructed altered what he saw and how he understood what he saw (a fact crucial to his understanding of nebulae as progressively developing cloudlike material).[30]

Herschel's view of instrumental work as an intimate, skillful collaboration was theorized in quasi-biological terms a generation later by the Prussian polymath Alexander von Humboldt, who saw scientific instruments as outgrowths of human capacities:

> The creation of new organs (instruments of observation) increases the intellectual and not infrequently the physical powers of man. More rapid than light, the closed electric current conveys thought and will to the remotest distance. Forces, whose silent operation in elementary nature, and in the delicate cells of organic tissues, still escape our sense, will, when recognized, employed, and awakened to higher activity, at some future time enter within the sphere of the endless chain of means which enable man to subject to his control separate domains of nature, and to approximate to a more animated recognition of the Universe as a Whole.[31]

The instrument merges with and extends our senses, and unites us in thought and in action with the cosmos. Both Herschel and Humboldt presented the use of instruments as a "dance of agency" akin to that which Andrew Pickering describes as "the mangle of practice."[32]

Yet the reciprocal agency at work in the mechanical romanticism of Herschel and Humboldt is certainly not the only way in which the activity of instruments has been understood. One classic understanding is of the instrument as entirely passive. In the case of music, one thinks of instruments perfectly responsive to the impulses of performers. Science maintains the dream of the "transparent" instrument, one that renders, in a known and entirely predictable way, the givens of nature. In the late eighteenth century, the balance, as used across diverse sciences (in the form of scales, calorimeters, and economic balance sheets), implied an equivalence of inputs and outputs, with no interference by the instrument.[33] The nineteenth-century scientific ideal of "mechanical objectivity," which focused on devices that bypassed the peculiarities of human intentions and will, likewise assumed that machines would passively transmit the world out there, a mediation that in no way altered the phenomenon being observed.

At the opposite extreme we find expressions of concern that the unsought agency of an instrument will upset the delicate equilibrium between observer and world: the history of twentieth-century science evidences constant worry about the artifacts and noise produced by observing machines, from bubble chambers to functional magnetic resonance imaging machines (fMRIs)—traces not of the object being studied but of the experimental apparatus itself. In music, the recurring figure of a self-

[30] See Simon Schaffer, "Herschel in Bedlam: Natural History and Stellar Astronomy," *British Journal for the History of Science* 13, no. 3 (1980): 211–39.

[31] Humboldt, *Cosmos: A Sketch of a Physical Description of the Universe*, vol. 2, trans. E. C. Otté (London, 1849), 742. Humboldt presented instruments as active organs throughout *Cosmos*; he described the telescope as having "exercised an influence similar to some great and sudden event" (739).

[32] Pickering, *The Mangle of Practice: Time, Agency, and Science* (Chicago, 1995).

[33] Norton Wise, "Mediations: Enlightenment Balancing Acts; or, The Technology of Rationalism," in *World Changes: Thomas Kuhn and the Nature of Science*, ed. P. Horwich (Cambridge, Mass., 1993), 207–56.

playing instrument frequently involves diabolical deals, magical flutes, and uncanny hunting horns; the negative associations of this myth are active today in denunciations of lip-synched performances as soulless and robotic.[34] Daft Punk—a French electronic dance music duo who perform in helmets making them look like robots—make intriguing sport of this topos. Their 2006/7 *Alive* tour featured synchronized light patterns, beats, and vocoder phrases emanating from a giant illuminated pyramid, a spectacle whose preprogrammed nature in no way diminished the crowds' delight. Charisma and spontaneity were paradoxically presented as being on the side of the machine, provoking an ironic recognition that all participants in the event — performers, audience members, and technical apparatus—were "human after all," as in the title of Daft Punk's 2005 album.

In performance, agency may also shift among different instruments working together. In a jazz session's call-and-response and turn taking, one instrumentalist moves forward as soloist, improvising freely, while the other members of the combo maintain a steady background; the soloist retreats and a member of the background comes forward to work a new melodic line. The cuing required for taking turns involves an intersubjectivity that is all the more complex the more an ensemble tends toward the outer limits of free jazz, where all improvise at once.[35] In a scientific experiment, the management of agency is also at a premium. The ideal of a statistical experiment, for instance, involves control over the agency of all elements except one: the independent variable. This widely held conception of the mode of mediation in the elements of an experimental system (with multiple controlled variables, a single independent variable, and a single dependent variable) arises from the conjunction of early nineteenth-century writings on scientific method with late nineteenth- and early twentieth-century statistics. A new organology would explore the historicity of this and related formulations of instruments' modes of mediation, examining the prevailing understandings and evaluations of instruments' degree of agency in a given period and field.

MAP OF MEDIATIONS: EXPERIMENTAL SYSTEMS, ORCHESTRATION

So far, we've considered the elements that make up an instrument and their different possible arrangements; we've thought about whether instruments are seen as acting under their own impulses, or if they are entirely dependent on an outside agent, be it the human using them or some other force. A third dimension along which we can analyze and compare instruments in action is the location they occupy with regard to other elements: other instruments, the range of users involved with them, their objects, their audiences. In parallel with Foucault's notion of a mode of subjection—the subject's relation to rules and external obligations—for an instrument, this is a map of mediations.

[34] See, e.g., E. T. A. Hoffmann's short story "Der Sandmann" (1816) as translated by E. F. Bleiler in *The Best Tales of Hoffmann* (New York, 1979), 183–214. The story involves Olimpia, a piano-playing and deceivingly lifelike automaton who leads to the horrific downfall of the protagonist; Lisa Morales, "Ashlee Simpson and That Lip-Syncing Feeling," *Washington Post*, 26 Oct. 2004.

[35] Ornette Coleman, *Free Jazz: A Collective Improvisation*, Atlantic SD 1364, 1961, 33⅓ rpm; John Litweiler, *The Freedom Principle: Jazz after 1958* (New York, 1984). See also Arnold Davidson's keynote lecture, "Improvisation as Ethical Form," for the symposium "Improvisation and Ethics: A Conversation," held at Columbia University 13 Nov. 2008. The talk is available through Jazz Studies Online: http://jazzstudiesonline.org/?q=node/987 (accessed 29 Sept. 2012).

The history of science of the past thirty years has made the map of mediations articulated by an instrument a central topic. The ways in which points of a map may be adjusted, black-boxed, and revised are signaled clearly by Hans Jörg Rheinberger's "experimental system," which he defines as a "basic unit of experimental activity combining local, technical, instrumental, institutional, social, and epistemic aspects."[36] Many of the field's terminological innovations gesture in the same direction: the Foucauldian *dispositif* or apparatus, the "experimental assemblage," the "network." A handful of such systems have become paradigmatic. For instance, in seventeenth-century England, well-heeled gentlemen of the Royal Society gathered to observe facts produced by carefully regulated instruments, including Robert Boyle's air-pump, in experiments in Gresham College choreographed by Boyle. The scenography separated visible work performed by Boyle and other natural philosophers from the labor of "invisible technicians," the "lowly mechanics" who prepared the rooms, built and maintained much of the equipment, and assured the successful conduct of experiments. The diagram of the elements linked by the air pump thus included humans—the fellows of the Royal Society; the mechanics; the elements brought into contact with it (barometers, mercury thermometers, candles, and doomed doves); the architectural setting; and the extension of this time and space into other times and spaces through the virtual witnessing made possible by the reporting in the *Proceedings of the Royal Society*.[37] The instrument can be seen as the cornerstone of all these relationships. Similarly celebrated is the laboratory of Louis Pasteur, with its exemplary experiment involving two swan-necked flasks containing beef broth. After the swan neck was broken off of one of them and exposed to the air, tiny organisms grew in that solution, but not in the flask whose neck remained unbroken. The demonstration and explication of these flasks helped make Pasteur's lab "an obligatory point of passage" linking hygienists, the state, farmers, vintners, physicians, and thirsty schoolchildren.[38] Likewise, the arrangement of Franciscus Cornelis Donders's laboratory to correlate reaction times to cognitive events formed a map that articulated "partial objects derived from the experimenter and the experimental subject (eyes, hands, voices, etc.), more or less isolated organs (hearts, lungs, muscles, nerves, etc.), energy sources, styli, sooted paper, tables, notes, and publications."[39] As these familiar examples show, a map of mediations is not static but rather a chart of movement, a symphonic or choreographic transcription.

In music, two terms exist for this kind of complex organization: instrumentation and orchestration. The former describes the act of distributing musical material to instruments generally; the latter term is used in the specific context of the particular assemblage we know as an orchestra. The instrumentation or orchestration of a particular piece of music depends upon numerous factors, ranging from the aesthetic to

[36] Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, Calif., 2007), 238. Rheinberger's sense of the importance of procedural rules in an experimental system, as well as his division between "technical objects" (elements that remain fixed) and "epistemic things" (those that are subject to variation) suggests the close connection between a map of mediations and the specific mode of mediation of its elements.

[37] Steve Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*, 2nd ed. (Princeton, N.J., 2011).

[38] Bruno Latour, *The Pasteurization of France*, trans. Alan Sheridan and John Law (Cambridge, Mass., 1988).

[39] Henning Schmidgen, "The Donders Machine: Matter, Signs, and Time in a Physiological Experiment, ca. 1865," *Configurations* 13, no. 2 (2005): 211–56, on 211.

the institutional. That is to say, the fact that we can speak of "orchestration" implies not just the existence of orchestras but also standardization in what those ensembles are. The term itself was first used in the nineteenth century and reflected the consolidation of the modern orchestra as a musical body, an institution, and a concept (roughly contemporary with an emerging standardization of scientific laboratories and globally distributed observatories).[40] This transformation radically altered how composers could interact with instruments and the ways in which they wrote for them. In the late seventeenth century, wind instruments frequently doubled already existing string parts; in the early eighteenth century it was not uncommon for composers to write a generic upper line that either a flute or oboe could play. Over the course of the eighteenth century, the ensemble expanded to include more instruments and became relatively uniform across geographical regions. This stability meant that composers writing for the orchestra could write instrument-specific parts: parts for flutes, clarinets, and oboes would take advantage of the unique qualities of those particular instruments. By the early nineteenth century, it was expected that a piece of music for an orchestra would engage with the different voices of the ensemble in sensitive and effective ways. This involved knowing the technical capacities and limitations of each instrument and the effects that they could create when combined with each other. With this new way of engaging with the orchestra came a new kind of compositional aid: the instrumentation treatise. These documents were distinctly different from the organological treatises of the previous centuries, since they addressed both the collective practice of writing for instrumental combinations as well as the specific qualities of individual instruments. Earlier treatises on instruments, by contrast, had sought to classify and categorize instruments, often emphasizing their similarities rather than their differences.

Though instrumentation treatises existed in the eighteenth and early nineteenth centuries, these have been largely overshadowed by Hector Berlioz's *Grand traité d'instrumentation et d'orchestration moderne*.[41] Berlioz, in lively language, instructs his reader about the personality and characters of each instrument and offers examples of their most effective uses, drawn from contemporaries such as Giacomo Meyerbeer as well as his precursors (Gluck, Beethoven, etc.). But crucially, Berlioz also discusses the art of combining instrumental sonorities, imagining what an ideal orchestra would look like (the answer involves over eight hundred instrumentalists and singers) and what sort of powerful and otherworldly sonic combinations could be achieved by such an ensemble. Just as important as understanding the individual instrumental characteristics and their combinations was knowing how to control them. A large ensemble risked devolving into mere noise, without the intervention of an all-powerful composer-conductor who could coordinate the myriad parts of the ensemble (Berlioz famously likened the orchestra to an enormous keyboard instrument upon which the conductor played, and fantasized about synchronizing players via electrical telegraph). But Berlioz's conception of orchestral music went beyond instruments and the conductor: equally crucial were the space in which the orchestra

[40] On the history of the orchestra as an institution, see John Spitzer and Neal Zaslaw, *The Birth of the Orchestra* (Oxford, 2004). On the history of the idea of orchestration, see Emily I. Dolan, "Haydn's Creation and the Work of the Orchestra," *19th-Century Music* 34, no. 1 (2010): 3–38.

[41] Originally published in Paris, 1844; revised 1855; translated by Hugh Macdonald as *Berlioz's Orchestration Treatise: A Translation and Commentary* (Cambridge, 2002).

played (outdoor orchestral music, he argued, didn't really exist) and the arrangement of the players in relation to the audience.

Berlioz's treatise therefore alerts us to questions we might ask about instrumental collectives in both music and science: How do different instruments within a group relate to each other? How are they coordinated? What sort of spaces do they require? What institutions support the ensemble? Since the advent of electronic music in the 1920s, many issues surrounding instrumentation and orchestration have transmuted into questions concerning the arrangement of studios and experimental music labs; now, on top of asking about the relationship between individual instruments, we can ask additional questions: How is a particular studio constituted? What is the relationship between people developing new technologies and those producing music with those technologies? How do scientific and musical practices merge and distinguish themselves? In their article in this volume, Cyrus Mody and Andrew Nelson explore precisely these sorts of questions; indeed, their study of the institutional and political contexts of the Center for Computer Research in Music and Acoustics at Stanford traces a map of mediations very much in the sense we are proposing.

THE ENDS OF INSTRUMENTS

To what ends are instruments used? This question has already lurked behind many of the above discussions. The answer may seem obvious in the case of musical instruments: a musical instrument is intended to play music. But even beyond the vast range of uses and meanings of musical performance, it's also true that musical instruments have at various points been employed to nonmusical ends. Stepping beyond our limited Western focus for a moment, consider the *shakuhachi* flute, made from bamboo root. An instrument capable of extreme nuance and subtle shading, the shakuhachi flute is associated with a wide musical repertoire. In the Edo period, the instrument was used by the *komuso* monks, in the Fuke sect of Zen Buddhism, who played it as a means of breathing meditation. But these flutes served another purpose as well: shakuhachi flutes were also taken up by *ronin*, samurai warriors who lacked masters and were therefore forbidden to wear swords. Many became—or disguised themselves as—monks and carried and played flutes: the hefty, club-like flute in their hands became a useful and discreet weapon.

Even if we restrict our investigation of musical instruments to more traditional musical performances, we can still find a variety of intended ends. One use of trombones in baroque-era sacred music was as an instrument of coordination. The trombone could double vocal parts and thereby help the singers keep their pitch. In the late Enlightenment, we find a new use: in Mozart's *Don Giovanni*, the trombone enters as the sound of sacred authority, signaling the ghostly presence of Il Commendatore, whom the lascivious Don kills at the beginning of the opera. The trombone's meaning in Mozart's opera relied on its earlier function within the church; it was strongly associated with a sacred context, even if within that context it was not used to signal divine might.

Comparably, one historian of scientific instruments has jokingly diagnosed what he calls "the astrolabe syndrome": the difficulty of finding interesting things to say about the instruments most commonly displayed in science museums.[42] But as far

[42] Jean François Gauvin, "The Astrolabe Syndrome," *JFG: Carrière et vie professionelle* (blog), 9 Mar. 2009, http://jfgauvin2008.wordpress.com/2009/03/09/the-astrolabe-syndrome/.

as an instrument's telos goes—the overall projects within which it is inscribed, the ways in which it articulates humans' relations to each other and to the cosmos—astrolabes could hardly be more compelling. The fact that there are so many of them, making up a significant proportion of many collections, underlines the wide availability of this instrument. In the early modern period, astrolabes were of use to travelers, often on board ships driven by the tangle of motivations science historians have come to know well: the acquisition of commodities and specie, knowledge of the vast variety in the flora and fauna of diverse regions of the world, enhancement of the standing of the sovereign sponsor, the glorification of God and the spreading of his word, the extension of empire through trade, conquest, and settlement. Further, a great number of the historical astrolabes in science museums are of Islamic origin. Asking about *their* telos leads to consideration of Islamic theories of the four winds; the importance of natural philosophy as a means of worship; and the place of astrology in medieval Islamic courts. More vividly, the number and distribution of small, portable astrolabes, and the prominent markings on them that indicated the *Qibla*—the direction of Mecca—show them as tools of social coordination across vast distances. Five times a day, in a wave across the planet that follows the movement of the sun across the sky, the faithful conduct their prayers, aligned to a single point in space, thanks to this handy tool.[43]

Similarly, tracing the different projects within which an instrument is deployed over time may illuminate large-scale structural transformations in the aims of musical composition and performance. The organ, for instance, has a long-standing association with churches, cathedrals, and the liturgy; in the seventeenth century, the Jesuit natural philosopher Marin Mersenne investigated its mechanical properties as part of a project uniting worship with empirical and rational study: "Organs were the reification of Mersenne's universal harmony, a harmony juxtaposing the spiritual and the worldly, the music of pure consonances with the levers, gears and bellows of a mechanical device. To worship God while listening to the music of an organ or to discover God's natural creations by means of the latter's mechanical parts was not that incongruous to someone like Mersenne."[44] In the nineteenth century, Meyerbeer heightened the impact of his opera *Robert le diable* by employing an organ in the opera hall, a potentially risqué displacement from worship to entertainment.[45] A similar journey was traced in the twentieth century, when the Hammond organ, developed as a less expensive and smaller replacement for church organs, drifted from gospel to blues and jazz, due in large part to "The Incredible" Jimmy Smith's use of it on Blue Note albums including *The Sermon!* of 1958. The Hammond's overdriven sound powered Bob Dylan's momentous switch from folk to electric rock in 1965's "Like a Rolling Stone"; it became an evocative, vibratory mainstay of psychedelic

[43] Sarah Schechner Genuth, "Astrolabes: A Cross-cultural and Social Perspective," introduction to *Western Astrolabes*, by Roderick Webster and Marjorie Webster (Chicago, 1998); David King, *Astronomy in the Service of Islam* (Hampshire, 1993); "An Islamic Astrolabe," on the Starry Messenger website of the Department of History and Philosophy of Science, Cambridge University, http://www.hps.cam.ac.uk/starry/isaslabe.html (accessed 4 Apr. 2013).

[44] Jean-François Gauvin, "Music, Machines, and Theology (II)," *JFG: Carrière et vie professionelle* (blog), 15 Mar. 2009, http://jfgauvin2008.wordpress.com/2009/03/15/music-machines-and-theology-ii/.

[45] Emily I. Dolan and John Tresch, "'A Sublime Invasion': Meyerbeer, Balzac, and the Opera Machine," *Opera Quarterly* 27, no. 1 (2011): 4–31.

rock of the 1960s and '70s, and returned in the 1980s and '90s as a favored texture in acid jazz and hip-hop, an aural nod to soulful precursors.

Scientific instruments also serve many ends. They may be used in exploratory basic research or routine industrial production; like the thermometer, insulin meter, or calculator, they may be part of everyday domestic life. These differing modes of use make them part of different maps of mediation and connect them to different ends. In the eighteenth century, the instruments associated with Newtonian mechanics, including telescopes, Atwood machines, and electrical machines, were used to investigate properties of nature; they could also publicly demonstrate the truths of natural philosophy. These distinct modes and maps, however, shared a common telos: confirming Newtonian laws of nature as the basis of God's stable universe, and establishing natural philosophers as privileged interpreters of both divine and temporal laws.[46] In the nineteenth century, one could consider the role played by telescopes—John Herschel's in South Africa or Lord Rosse's in Parsonstown—in debates about natural theology, evolution, and multiple worlds, including the famous "moon hoax." Later in the century, French popular astronomer Camille Flammarion's telescope was a gateway to wonder for a mass audience. By the twentieth century the complex instruments of the observatory were put to work, worldwide, for national security, the space race, and the search for extraterrestrial life.[47] Whether we discuss church organs or telescopes, tracing instruments' changing aims, and the ways they articulated humans' relations to nature and to technology, may offer a revealing, perhaps counterintuitive shorthand for the technical and cultural histories of music and science over several centuries.

CONCLUDING INTERACTIONS

Exploring the history of music and science along the four dimensions we have sketched—material disposition, mode of mediation, map of mediations, and telos—aims to make visible the changes as well as the continuities in the ways in which instruments have been used and understood. In our scattershot examples, we have encountered several moments where the history of science and the history of music intersected. The ultimate aim of this study, of course, would be to make visible the historical patterns of these intersections. While we are still far short of an organological précis (or epic) of this sort, a handful of inflection points seem particularly promising for further study.

For starters, we might consider the long-standing close relation between music, astronomy, arithmetic, and geometry inscribed in the medieval quadrivium, united by Pythagorean conceptions of form and relation. At the same time, we could explore the variable relationship between the sciences of the quadrivium as abstract theories and the practices that accompanied them: these liberal arts concerned with form were traditionally set above and apart from the lowlier mechanical arts that concerned instruments and machines. At what points did the status of mathematical instruments and musical instruments change, and how did these changes correlate with

[46] Simon Schaffer, "Machine Philosophy: Demonstration Devices in Georgian Mechanics," in Van Helden and Hankins, *Instruments* (cit. n. 1), 157–82, on 160.
[47] See Morrison-Low et al., *From Earth-Bound to Satellite* (cit. n. 19).

changes in the theoretical sciences? For instance, a defining feature of early modern science was the shift of natural philosophy from a primarily contemplative domain to a field dependent on instruments and experimentation.[48] Might there be interesting comparisons between, on one hand, the relation of music as liberal art to music as performance, and, on the other, the relation of the sciences of arithmetic, geometry, and astronomy formerly associated with the quadrivium to the technical practices of mixed mathematics and experimental natural philosophy? How did the rising status of the mechanical arts in natural philosophy—as in Galileo's prominent use of the telescope—affect conceptualizations of musical instruments in early modern music theory?

Moving forward in time, we have elsewhere examined continuities and breaks between Enlightenment and romantic-era uses and representations of both scientific and musical instruments.[49] Along with several contributors to this volume, we might consider the intersection of the musical and scientific instruments in Helmholtz's laboratory, his studies of the ear and the eye, and his artificial production of stimuli to affect them. Focusing on the same period, however, we would further have to consider the ways in which understandings of music and science bifurcated. Baudelaire's famous attack in 1859 on photography as anathema to true art—which he believed to be concerned only with the imagination—was arguably embodied in Wagner's choice at Bayreuth to make the orchestra invisible in front of the stage: audiences might be distracted from the spiritual and idealist transports of his music and spectacle if they were forced to witness the instruments that made them possible. Later, the futurists' love of technology led them to break from musical idealism as radically as possible, with Luigi Russolo's *Art of Noise* manifesto: "We certainly possess nowadays over a thousand different machines, among whose thousand different noises we can distinguish. With the endless multiplication of machinery, one day we will be able to distinguish among ten, twenty or thirty thousand different noises. We will not have to imitate these noises but rather to combine them according to our artistic fantasy."[50] This ambition—and this new alliance between music and other technologies—continued into musique concrète. As we suggested at the beginning of this article, the tendency seems to have reached a new plateau in contemporary music: the MIDI sampler and subsequent music-composition programs that reproduce the waveforms of all existing musical instruments transform incidental sounds captured from any setting and produced by any means into musical instruments. The electronic archive of musical sounds becomes the potentially infinite supply source for cut-and-paste compositional practices, at the same time as scientific discovery is reconceived, across disciplines, as the automatic, algorithmic mining of vast, delocalized databases.

Such would be some of the turning points signaled in a longer story that could be

[48] Peter Dear, "What Is History of Science the History *Of*? Early Modern Roots of the Ideology of Modern Science," *Isis* 96 (2005): 390–406; see also Lissa L. Roberts, Simon Schaffer, and Peter Dear, eds., *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam, 2007).

[49] Emily I. Dolan, *The Orchestra Revolution: Haydn and the Technologies of Timbre* (Cambridge, 2013); John Tresch, *The Romantic Machine: Utopian Science and Technology after Napoleon* (Chicago, 2012).

[50] Russolo, *The Art of Noise: Futurist Manifesto, 1913*, trans. Robert Filliou (New York, 2004), 12.

woven out of the materials furnished by a more complete organology of music and science. We conclude with a more modest tale, one from a period when the techniques of beautiful sound and natural knowledge were also closely entwined and promised new experiences and a new framing of the world. Back in the 1770s, one of the founders of musicology, Charles Burney, made a number of trips around Europe to collect material for his famed four-volume *History of Music*. He visited church organs, encountered street music, went to the opera, and heard a variety of orchestras perform. At the same time, he carried out acoustical experiments, testing the properties of the echo in the Villa Simonetta on the outskirts of Milan; he sought out and admired a grand orrery built by Matthew Hahn; and he visited the Jesuit scholar and astronomer Roger Boscovich and the physicist Laura Bassi, both of whom demonstrated for him their instruments and machines, much to Burney's delight.

For Burney, to understand music *and* physics, opera *and* astronomy, one had to have firsthand experience with the instruments involved in their execution and performance. Burney further declared that with more time he would have gone beyond musicology to create a journal dedicated to "the present state of arts and sciences, in general."[51] A new organology could underwrite such a project, allowing it to embrace a wider history, curating, concretizing, and animating it with the multifarious objects that reside (though often far apart) in museum collections. Now, at a moment when all sounds and phenomena are portrayed as collapsing into a single medium of easily convertible data, music scholars and historians of science can gain by retrieving some of Burney's avid, eye- and ear-witness attention to the concrete spaces, routines of practice, community formations, and creative lines of flight in both musical and scientific forms of life. In exploring what we have been calling the ethical specificities of the instruments that hold such arrangements together, they can begin once more to measure out the discords and harmonies between these fields.

[51] Charles Burney, *The Present State of Music in Germany, the Netherlands, and United Provinces*, 2 vols. (London, 1775), 2:332.