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SPECTRAL MUSIC

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Spectral Music is an approach to instrumental composition that uses insights gleaned from electronic music, acoustics and psychoacoustics as well as tools from computer science in order to fundamentally reconsider the technology of instrumental musical composition. Thus, it illustrates challenges and opportunities innovators will face when they seek to build new art forms on a scientific basis. In spectral music, Gérard Grisey, Tristan Murail and their colleagues created a New Paradigm for musical composition, that others can emulate in their own fields.

Forward, Back, or Turn Left

For composers coming of age in the 1960's, the landscape of contemporary music was riven by a seemingly insurmountable divide that obscured all other points of divergence or agreement. This divide concerned the importance of musical progress and innovation versus an expression-centered view—in other words, the conflict between modernism

and post modernism.

Modernists tended to view "musical progress" and technical or aesthetic innovation as the very purposes of art, while post-modernists tended to view ideas of progress and teleological history as a will-o'-the-wisp that created a class of intellectual charlatans who masked their "musical failings" in a pseudo-scientific garb designed to hide their irrelevance. Composers, faced with this decision, aligned themselves on either side, and this alignment conditioned nearly every aspect of musical life, from the music one wrote or listened to, one's supporters and enemies and even the terminology used to discuss music. This debate was often posed in hyperbolic terms which suggested that one had to choose between significance and meaning, and that beauty and relevance were somehow mutually exclusive. A post-modernist like George Rochberg describes the modernist approach as having been "proved to be bankrupt" (Rochberg 1984, p. 404), while a modernist like Tristan Murail believes that "all examples of 'retro' styles, [are] fundamentally sterile" (Murail 2005a, p. 122).

This choice led to a broad host of other issues, including where an innovation should happen (in the modernist view) or what pre-existing templates of style and expression would communicate one's music most effectively (in the post-modernist view). Ironically, as vastly divergent as these two paths often seemed, both sides mostly left in place the very same musical infrastructure that is the inherited legacy of 400 years of musical history. Music was generally considered on a historical continuum of chromaticism where one could choose to go forwards, to fully chromatic music where all 12 pitches were close to equal and complexity was the watchword, or backwards, to diatonicism where only the most consonant pitches occur with any frequency and

simplicity and "expressiveness" are the goals (in the post-modernist view, one would most likely have seen this as a circle rather than a line, but still a one dimensional surface).

However, beginning in the late 1960's in France, a group of young composers led by Gérard Grisey and Tristan Murail began writing music (and performing it with their ensemble l'Itinéraire) that was to fundamentally alter these assumptions. They began looking for novel, even innovative ways to organize music that were directly related to human perception. In a certain sense, they found a way to break free of that one-dimensional axis and turn left, opening up a vastly larger space of possibility. Over the last 40 years, this music (which has come to be called Spectral Music) and its innovations have fundamentally altered many of the common assumptions underpinning the apparent diversity of 20th century music. Moreover, they have shown that the apparent contradiction between innovation and expression is a false dichotomy when innovation is tempered by an understanding of perception and a clear appraisal of the sonic structures that an audience actually hears, rather than the symbolic structures a composer might manipulate during the compositional process. To varying degrees, these innovations have affected composers across a vast spectrum of styles and orientations. However, before we can look at the specific innovations and how they came about, it will be necessary to offer some context for those not deeply familiar with how composers write music.

The Technology of Musical Composition

For much of the last 400 years of history in the field of what I shall call "Western Art Music," there has been a basically unified technical apparatus for writing music. The

apparently great stylistic transformations that led from the restrained Classicism of late 18th century music to the sweeping Romanticism of the middle 19th century were much more changes in inflection, tone, and scale, than fundamental changes to the relationships and techniques that composers use to build their pieces. This is true to a degree that may seem startling to those outside of music. That technical consistency was not the result of strong conceptual or theoretical framework used to train and indoctrinate composers. In fact, most of the theoretical constructs of music theory came into being long after the music to which they refer. Instead, the main mechanism for this technical consistency was the apprentice-like training process that focused on imitation of existing works with increasing personalization of materials, but without fundamentally questioning the orientations and assumptions of these models (or questioning them in limited ways from within their world-view). Just as generations of novel writers wrote new works without questioning the basic literary, linguistic, or often even formal tool-kits of their forebears and painters copied masterworks as a way of learning basic tools like perspective and representation, composers during this long period thought about *what* they wrote without asking deeper questions about *how* they wrote.

In music, this ubiquitous set of techniques became clearly defined only through hindsight, long after artistic practice had become very highly consistent. Music theorists looking back at these techniques as used by the full range of composers from the 17th century though the early 20th century gradually elaborated the widely shared but at the time unevenly formalized technical apparatus that has come to be called the "common practice." Moreover, that entire time span has come to be called the common practice era or period. The technical details of this common practice go beyond the scope of this

essay, but it is important for our purposes to understand these traditional techniques were not driven by theory. Music theory as it relates to this historic repertoire is "not a set of directions for composing music. It is rather the collected and systematized deductions gathered by observing the practice of composers over a long time, and it attempts to set forth what is or has been their common practice. It tells not how music will be written in the future, but how music has been written in the past" (Piston 1941, p. 1). However, music theory, or perhaps more accurately theorizing about music, was to take on a much more prominent role in shaping compositional practice in the 20th and 21st centuries.

The very notion of employing a unitary "common practice" of almost any kind becomes anathema to those seeking something more akin to "individual" expression. Moreover, as the traditional apprenticeship-like training (driven mostly by varied imitation of historical works) seemed increasingly ill-adapted to many composers' quests for "innovation" and "novelty," speculation became a more important driver of musical technology. Thus, more and more composers turned to prospective music theories as a way of looking forward. A new type of musical theory moved away from the post-hoc descriptive music theory of common-practice music into a prospective field of what might be called theoretical composition. The value of these theories, therefore, is often (but not always) judged more on their applications within pieces of music, than on their abstract conceptual merits. In an extreme though not uncommon implementation, this can mean the development of large-scale theories for the sake of being able to build a single work upon the theories, with little or no applications beyond that one piece of music.

Prospective musical theories during the first six decades of the twentieth century covered a broad range of musical issues and styles. For the sake of this essay, though, I

would like to divide this cornucopia of conceptualizations into three major categories, each containing a whole range of very different composers and theories. Though this way of parsing the very heterogeneous landscape of early and mid-twentieth century music is by no means standard, it does capture the essential intellectual features of the dominant musical trends through the 1960's (and beyond) and will allow the music/technological innovations of the Spectral Movement to be put into their proper context.

Combinatorial theories look to create "language" through permutation and relation, seeking to replace the hierarchical organization of tonality with a relational/relativistic system. Within relational/relativistic systems, like the combinatorial framework created by Arnold Schoenberg, Anton Webern, and Alban Berg (often called serialism), there is no pre-established hierarchy; whereas in a tonal work, pitches are strictly organized by their "function" within the "key" using a preexisting framework. As Schoenberg proclaimed, the dissonances have been "emancipated." The absolute pre-learned framework of the common practice is replaced by intervallic and combinatorial structures that are developed for and within a given work. Coherence and consistency become intrinsic properties of each work, generated by the local compositional processes. This abandons the inherited and previously omnipresent frameworks of tonality and common practice forms. What remains stable from piece to piece is no longer the actual musical relationships, but a panoply of compositional processes that yield those relationships.

Conceptual theories question the very nature of what music is, what its social/political functions and obligations are, and even whether music should be driven by authorial intent at all. An extreme example is John Cage's *4'33''* which is made up of

three movements of complete silence in which "music is reduced to nothing, and nothing raised to music. It cannot be heard and is heard anywhere by anyone at any time" (Griffiths 1995, p. 28). These theories are closely allied with movements in others artistic disciplines, like Bauhaus, or Fluxus. Musical compositions, in this view, are primarily a means of exploring the boundaries of musical meaning or the social impacts and effects of music. Music becomes a vehicle for conceptual art rather than an artisanal craft. As with combinatorial theories, there was a strong desire to leave behind earlier art's relationship to social hierarchies by striking out against rigidly imposed conventions of all sorts. According to Cornelius Cardew, a leading member of this movement, "The ideology of a ruling class is present in its art implicitly; the ideology of a revolutionary class must be expressed in art explicitly" (Cardew 1974, p. 86). In this view, music is more a means of conveying abstract ideas than a traditional aesthetic object.

Repertoire oriented (post-modern) theories seek to establish a dialogue with other music or musical traditions. In this view, current works exist in a "meta-dialogue" with works from the past. As such, an enormous part of the compositional process is sculpting a new work's relationship with other pre-existing works and repertoires. Composers working in this vein often reject the modernist impulse for re-invention and instead speak of personal expression or of continuing and re-interpreting traditions. Some composers working in these veins may seek to fuse disparate traditions, while others may seek to broaden from within, or simply to make works that eschew the need for "linguistic" novelty completely. The writings of these composers often express a sentiment of returning to something that has been lost and there is often a great deal of nostalgia for common practice tonality. However, unlike the music actually written during the

common practice era, the theoretical framework in which this music is written had been very specifically taught to these composers in formal theory classes and the decision to use common practice techniques and forms is an affirmative gesture in a way that it could not have been when common practice was not a choice, but an assumption and an inevitability. Moreover, music built from the deliberate juxtaposition of disparate historic styles and musical genres is quite distinct from the music initially produced in those styles or genres. Though this music has often been very successful with the public, it has often been looked down upon by composers from both of the more speculative trends mentioned above, and has often responded to this disapproval by adopting a slightly anti-intellectual and highly anti-modernist rhetoric. George Rochberg, an intellectual leader of the neo-Romantic movement, expresses the movement in this way: "The acceptability of such a work hinges no doubt on whether one is able to reconcile a juxtaposition of musically opposite styles. In order to effect such a reconciliation, one has to be persuaded, first, that the idea of history as progress is no longer viable and, second, that the radical avant-garde of recent years has proved to be bankrupt" (Rochberg 1984, p. 404).

As different as these ideas and theories are, the vast majority of music produced with them tends to maintain many of the basic assumptions of the common-practice era. These holdovers are sometimes intentional, as when certain post-modern works make explicit stylistic references; however most of them are so deeply ingrained in our musical technology and training that composers often did not realize they were even choices. The most striking of these assumptions is the parsing of a sonic continuum into notes and rhythms. As Tristan Murail states, "Musical structures of the past (tonal, serial, etc.) fail

to account for intermediate categories because they force acoustical reality through inexorable sieves" (Murail 2005a, p. 124). In spite of all of their ideological differences, composers wrote almost all of the music described above using the same set of tempered pitches and intervals that had originally been developed to allow common-practice composers to modulate between different key areas within the hierarchical tonal system. They preserved a notational system that was highly optimized to those categories as well. Though there were a few notable exceptions, these commonalities remained quite close to universal. Even composers who tried to experiment with micro-tonality generally did so using the very same notions of interval structure (simply improving the resolution of the renditions). However, since at least the early 1950's, acoustic analysis, electronic synthesis of sounds and even honest introspection had made it clear that many or most of the sounds in the world do not fit into these neat, easily notated categories. Moreover, there are other categories of sonic organization, such as timbre or contour, that are much more salient to listeners, in a general context, than interval ordering, motif or other attributes that had become so important in the specific context of the common-practice.

The one area in which these categorical boundaries were necessarily breached was in the immerging world of electronic music. In this, mostly non-notated, music, composers were either manipulating recordings of real-world sounds or synthesizing new sounds (often through techniques that combined once distinct sounds into compound objects with a unitary perception). Being freed from the score but constrained by acoustic reality, composers like Pierre Schaeffer would describe their materials in terms of "sonic objects." This kind of thinking helped elucidate "the very essential idea that the musical 'atom' is not the notehead written on staff paper. The musical atom is the perceptual atom

. . .” and that “It is possible as well that there is no perceptual atom, that music is indivisible, that we perceive only flux (to borrow an image from theories interpreting light in terms of waves, rather than particles)” (Murail 2005a, p. 123). Prior to the innovations of the Spectral Movement, it was not at all evident how or even whether these insights might be applied within the realm of notated instrumental concert music. There were some limited attempts to imitate the textures and movements of electronic music in the late 1950’s and 1960’s, but they did so largely through accumulation of enormous masses with its concomitant perceptual overload, but without a guiding theory. The fundamental change wrought by Gérard Grisey, Tristan Murail and other composers who would follow in what has come to be called the Spectral Movement was the realization that a new insight into sound would require a fundamental change in the theoretical/compositional framework used by composers. Over the last four decades, the technological innovations of this new framework have fundamentally altered the way almost all composers manage the interaction between sound and structure in their music. In one of Murail’s classic polemics on the need for a new approach to composing, he explains the necessity for fundamentally revising the technology of musical composition:

> The current explosion of the world of sounds, and the techniques of investigating them, naturally raise questions about compositional systems. Limitations disappear, traditional classifications lose their meaning, and allowance replaces circumspection. The analytical approach (the decomposition of sound into parameters) no longer holds, and the traditional processes of Western music—combinatoriality, counterpoint of lines, permutations, imitations, etc.—lose their power

> when faced with continuous phenomena. A generalized approach becomes necessary to attempt to understand sound in all its complexity, all its freedom, to create the rules of organization required by any act of composition. But these rules need not be incompatible with the nature of sounds; we must accept the differences, the hierarchies, the anomalies, and resist, as much as possible, reductive analysis. (Murail 2005d, p. 150)

The craft that takes sound as its point of departure is not a pursuit of 'beautiful sounds' as is sometimes alleged. It rather tries to create a method of communicating clearly with sonic material; timbre is simply one of sound's most charged and recognizable categories. Here lies the importance to musical discourse of combinations of frequencies (which produce timbre). Of course one can find examples of spectral music with 'beautiful sounds,' but spectral music has also bestowed the history of music with some of its most atrocious noises. Really, it's not the intrinsic quality of a sound that matters; what matters is introducing systems of hierarchy, magnetization, or directionality into sonic phenomena in order to create a musical rhetoric upon a new foundation. (Murail 2005d)

In Situ

There is nothing unique in the early backgrounds of Murail and Grisey that would suggest they were on a path to fundamentally alter musical technology. Both Tristan Murail and Gérard Grisey were born in France in the mid 1940's, and though they took different routes, both of them attended the top national conservatory in Paris and studied

with the preeminent composition teacher of the 20th century, Olivier Messiaen. They both had strong backgrounds in performance, and Murail was an experienced performer on the Ondes Martenot, an early analog electronic instrument. Yet from early on in their compositional training, neither Murail nor Grisey were happy with the choices that seemed available to composers of their generation. The choice of following either a post-modernist or modernist path was not a satisfying choice for either composer. Both were committed modernists ideologically, yet both of them were looking to do things that the rules of the day said modernists were not allowed to do. They wanted to be able to imbue music with many of the properties it had had in the common-practice era: directionality, tension/release, memorability, etc. but they wanted to do this in novel ways, not through a post-modern return to proven historical techniques. Moreover, they were hoping to take advantage of the elongated, smooth sense of time that had begun to be imported from non-Western musics. To accomplish these goals, they needed to create a speculative framework that focused on the effectiveness of the result rather than the elegance of the formalization. Tristan Murail describes this search:

> While I was studying at the conservatory with Olivier Messiaen in the 1970s, the influence of the serialists was still predominant—even with Messiaen, who insisted that we work serially and forbade the use of octaves. I tried this for a while, but then realized that these techniques weren't suitable for what I wanted to express in my music. I thus tried to disengage myself from the serial school and at once attempted to find strong, pure harmonic colors, for serial composition very often leads to a sort of uniform grayness in the harmonic dimension. I also searched for a

> different approach to time: in particular, a non-event-oriented time. All this (and also the influence of Xenakis, his way of seeing music as an architecture of time and the orchestra as a mass which one could sculpt) led me to compose very differently. (Murail 2005b, pp. 181-182)

The problem of "composing very differently" still existed, though, especially since, in Murail and Grisey's views, most attempts at building a new compositional world after the post-World War II tabula rasa had failed. Though they did certainly draw somewhat on other composers of the day (especially Xenakis, Ligetti and Stockhausen), the primary answer for them was to go back to what they saw as the basic material of music: sound.

Composers like Giacinto Scelsi and Edgar Varèse had already begun thinking about sound. For Scelsi, "the principal object of composition then becomes what he calls the 'depth' of the sound. It is primarily a question of working with timbre, taken in the broadest sense: the global timbre of the orchestra as a whole. The composer is thus concerned with dynamics, densities, registers, internal dynamism, and the timbral variations and micro-variations of each instrument: attacks, types of sustain, spectral modifications, and alterations of pitch and intensity." (Murail 2005c, p. 175-176). However, those experiments were largely intuitive efforts; they did not seek to make a new compositional technology.

Claudy Malherbe sees this return to "concrete materials" as being closely parallel to the equally revolutionary path taken by the impressionist painters in the late 19th century, including that same process whereby initial intuitive experiments later yield to new techniques and conceptual frameworks:

> Like their predecessors who opposed official art connected with the École des Beaux-Arts and painters exhibiting in salons no less official, the Itinéraire musicians of the 1970's also turned their backs on what was the predominant musical esthetic of their period: the Darmstadt School's conception of serial music. In both cases these artists concentrated their attention on concrete materials, thus renewing their artistic vision: the painters liberated a new palette of colors in focusing their attention on light and the musicians liberated instrumental timbre in focusing their attention on sound. Moreover, the initial steps of these radical developments, both spontaneous and intuitive, were quickly bolstered by the artists' appeal to scientific fact. (Malherbe 2000, p. 16)

Gérard Grisey asserts that: "We are musicians and our model is sound not literature, sound not mathematics, sound not theatre, visual arts, quantum physics, geology, astrology or acupuncture." (Fineberg 2006, p. 105) "Our model is sound"—the spectral model is not built on traditional pitch structures, or rhythmic structures, or any other symbolically represented musical structure with all of their implicit assumptions about how sound should be parsed and manipulated. The spectral model is sound itself and the spectralists felt the need to look to sound for models of organization which are based on acoustics and perception, rather than on historical assumptions that may no longer be relevant. However, all of this rhetoric might have remained more positioning and publicity spin than genuine innovation except for two developments in the early 1970's that set the stage for the deep innovations of Spectral Music.

In 1973, Tristan Murail founded the Ensemble l'Itinéraire with Michaël Lévinas

and Roger Tessier, who were joined a short while later by Hugues Dufourt and Gérard Grisey. Somewhat ironically, as the Ensemble l'Itinéraire was performing music far outside of the mainstream, l'Itinéraire began receiving a significant government subsidy in only its second year. The government official in charge of musical subsidies in France had been looking for a way to undermine the intellectual institutional hegemony of Pierre Boulez and his ensemble the Domaine Musicale and, while that official's real sympathies ran more post-modernist than anything else, it was not politically viable to support music that was viewed as "reactionary." So the proto-spectral, very non-academic performances of l'Itinéraire, with the support of mainstream figures like Messiaen and a strong intellectual discourse behind their approach seemed like an ideal counterweight to Boulez and his more academic music. The Ensemble l'Itinéraire gave these composers an ideal musical laboratory. Especially in its earliest days, the Ensemble L'Itinéraire was a place where a fairly close-knit group of composers and performers (most of the composers were also performers) could try out new ideas, retaining the successes and eliminating the failures. The most striking and successful results of these experiments could then be used in final compositions. This sort of experimentation was central to the working method of L'Itinéraire.

The second key development occurred in 1974–75, when Gérard Grisey studied acoustics with Emile Leipp at the University of Paris VI. This allowed him to come into contact with analogue sonograms of instrumental sounds and gave him a taste of the burgeoning sciences of psychoacoustics and perception. It was at this time that Grisey wrote and premiered with l'Itinéraire the first truly spectral work, *Périodes*. He used acoustic notions like harmonicity and inharmonicity as broader intellectual frameworks

for musical categories like consonance and dissonance. He created gradual transformations between noise and pitch as a way of generating directionality. Harmonic aggregates could be modeled on the interior microscopic structure of a sound.

"*We are musicians and our model is sound . . .*" As elements of acoustic theory were gradually engineered into useful musical techniques that were field-tested and diffused to other composers, performers and the general public by the performances of the Ensemble l'Itinéraire, a new sort of musical technology came into being. Over the years, that technology expanded and led to other major innovations like computer assisted musical composition environments and a significant expansion of instrumental technique as a broad range of ensembles began performing this music regularly. However, at its root was this fortuitous synergy of theory and practice that allowed such a radically new way of parsing the sonic continuum to come about.

Spectral Techniques, Examples, and Effects

This section will feature a more concrete examination of a small part of the actual content of spectral innovations and how these composers conceive and produce their music. As mentioned earlier, many of these ideas grew out of a "post-electronic" view of music in which sounds are no longer divided into arbitrary bundles of dissociated parameters and where instruments can act as sophisticated sonic generators, in an "instrumental synthesis." Sound exists as continuous variations in air pressure and looking at these vibrations, there are few, if any, clean boundaries or unambiguous divisions, yet music had, for hundreds of years, cut these continua into regular grids of pitch or rhythm. These general statements require a good deal more specific information in order for them to

become genuinely meaningful. A brief summary of some of this information will be attempted here for the non-specialist (Fineberg 2000a).

Note vs. Sound

The most basic change wrought by spectral thinking is eliminating the idea of the abstract "note" as the basic unit of music rather than an actual physical sound. Traditionally, composers are taught to think of pitch as the primary meaningful category and then the "orchestration" of that pitch (its attribution to one or more instruments in an ensemble) as a sort of detail that does not fundamentally alter the structural role of the object. This is what allows one to "arrange" a piece for multiple sets of instruments while still thinking of it as the "same." Yet that "sameness" is only possible within a very strong framework of musical conventions, since the actual sounds made by two ensembles are in fact profoundly different. One example of this is spoken language. In a language one speaks fluently, it is easy to recognize two speakers with very different voices as saying the same thing, but if one hears the same words from two different speakers in a completely unfamiliar language, it will be almost impossible to ignore the register and cadence of the speaker's voice and recognize the utterance as "the same."

In this same way, the end of the common practice era made the note/sound dichotomy much less relevant. Acoustics reveals that notes, or really sounds of almost any sort, are almost always complex objects with numerous (sometimes very numerous) components and disparate behaviors over time. The relational structure of those components allows our mind to group them into a unitary percept with various characteristics. For example, sounds that are considered pitched, have the majority of their energy organized in integer multiples of the perceived frequency, called the

fundamental. The relative distribution of energy makes that pitch appear brighter or darker, more or less pure. Therefore it seems evident that the more salient unit is the perceptual object, which might well be the combination of several sounds into a hybrid "note."

Harmony vs. Timbre

In traditional terms, harmony refers to simultaneous sounding notes that form a simultaneous aggregate. However, if one thinks about notes as the complex bundles of component sounds that they are and aggregates as group of groups of components, it becomes clear that the line between a hybrid "sound" and a harmony is not so clear. It exists more as a continuum of perceptual fusion. When all the simultaneous sounds are grouped by our perception into one acoustic image, it might make sense to speak of the result as a timbre, while if the result can still be easily parsed into sub-units, one might call it a harmony. The boundary is so porous that it might come down to the amount of reverberation in the room or the quality of instrumental blend among the players. This ambiguity between harmony and timbre has led many composers in recent years to begin using the term harmony-timbre, to denote an aggregate that is somewhere between a collection of separate notes and a fully fused compound object.

The notion of timbre is important because our perception of timbre is so much more precise than our perception of abstract pitch and interval categories. For example, it is easy to recognize the voice of one's mother, even over a bad phone connection. Experiments have shown our timbral perception to be incredibly rapid and robust (perhaps because we use it to perceive speech vowels) while most listeners and even many college music majors really struggle to recognize intervals reliably. Therefore it

seemed evident that if one were seeking a way of creating novel materials that were nonetheless highly memorable and salient, timbre might offer an ideal model. Timbre is a notion that has interested composers for hundreds of years and is discussed at great lengths in studies such as orchestration books. However, that interest nearly always viewed timbre as a secondary phenomenon. Moreover, really understanding how timbre works requires more precise tools than introspection and experience. It was during his time at Paris VI that Grisey began to come into contact with sonogram machines. These machines use a rapid series of overlapping Fourier Transforms to analyze the makeup of complex sounds. The availability of these more powerful "sonic microscopes" was critical in the development of new musical models. The complexity of spectral language grew as analytical tools became more powerful and accessible, but they were essentially all based on the same technology of the FFT.

Looking Inside Sounds

French mathematician Jean Baptiste Joseph Fourier (1768–1830) showed that any periodic waveform could be decomposed into the sum of a series of sine-waves whose frequencies are at integer multiples of a fundamental frequency with different amplitudes and phases. This is called a Fourier Transform, since the periodic function is transformed into an equivalent Fourier series. While, in theory, the periodic function must be infinite, in practice, several periods of stability are enough for an accurate, though not perfect (in the sense of being able to reconstruct an exactly identical waveform) analysis. While the technique in its pure form can create only harmonic spectra, the use of extremely low "pseudo-fundamentals" allows a good sampling of the spectral energy throughout the auditory range—providing a close approximation of even very non-harmonic sounds.

To perform this calculation on an audio signal, an optimized discreet version of the Fourier Transform called a Fast Fourier Transform (FFT) must be used and a window of sound must be selected for analysis. In order to see the changes within a sound over time, a series of FFTs with windows that advance in time is necessary. Devices like the sonogram machine Grisey saw in Leipp's lab are able to analyze a sound using this technique of FFTs with overlapping windows which advance in time and create a representation of the sound as it evolves. Under optimal conditions, this representation is sufficiently accurate that it can perfectly recreate the sound.

Frequency Based Harmony

Viewing sounds as they appear through the lens of frequency analysis (as bundles of fused component frequencies), not as unitary conceptual atoms, naturally opened the door to the generation of harmonic and timbral musical structures based upon these frequencial structures. The frequency of a pitched sound is the number of times that its regular pattern of compressions and rarefactions in the air repeat each second. This value is expressed in Hertz (Hz) or cycles per second. Contrary to the linear structure of notes and intervals, where distances are constant in all registers (the semitone between middle C and D-flat is considered identical to the semi-tone between the C and D-flat three octaves higher), the distance between the frequencies within the tempered scale and the potential for pitch discernment of the human perceptual apparatus is neither linear nor constant: it changes in a way that is completely dependent upon register. Viewing structures from the perspective of frequencies gives access to a simple understanding of many sounds (like the harmonic spectrum) whose interval structure is complex, but whose frequency structure is simple. It is also extremely useful for creating sounds with a

high degree of sonic fusion, since the ear depends on frequency relations for the separation of different pitches. Further, a frequency-based conception of harmonic and timbral constructions allows composers to make use of much of the research in acoustics and psychoacoustics, which look into the structure and perception of natural (environmental) and instrumental sounds, providing models for the way in which various frequencies are created and interact to form our auditory impressions.

Additive and Instrumental Synthesis

The perspective described above gave spectral composers access to a whole host of frequency-based structures that might serve as harmonic/timbral models. Some are abstract, like the harmonic series, some are based upon the analysis of natural sounds, and some are extrapolated from mathematical models of sound. Probably the clearest, most intuitive expression of how one can employ these sonic models in musical structures comes to spectral music from the electro-acoustic technique of additive synthesis. In this technique, the simplest possible sonic components are used: sine waves. Fourier's Theorem states that any sound can be decomposed into a number of sine waves (in some cases, however, this may not be a finite quantity) and also provides the corollary that the combination of these elementary units can rebuild the original sound. The technique of additive synthesis applies this principle, building up complex sounds through the combination of a large number of elementary ones (sine waves). This technique is extremely powerful, in principle, since any sound can theoretically be synthesized in this way. In practice, however, it is often not that simple. But the technique, nonetheless, provides most intuitive way for us to conceive of hearing and creating sounds. By listening closely to any sound, it becomes possible to hear the

separate components, and, by adding sounds together it is easy to hear the global sound color, or timbre emerge and evolve.

By taking this concept of additive synthesis (the building up of complex sounds from elementary ones) and using it metaphorically as a basis for creating instrumental sound colors (timbres), spectral composers opened up a new approach to composition, harmony and orchestration. This is, perhaps, the most important idea to emerge from early spectral music. The sound complexes built this way are fundamentally different from the models on which they are based, since each component is played by an instrument with its own complex spectrum. Thus the result is not the original model, but a new, much more complex structure inspired by that model. The sounds created in this way keep something of the coherence and quality that comes from the model while adding numerous dimensions of instrumental and timbral richness and variety. The potential use of the same model for generating synthetic sounds (through additive synthesis) and orchestral ones (through instrumental synthesis) is also a reason why mixed electronic and acoustic music has played such an important role in the output of spectral composers.

Microtones

If a composer intends to use frequency-based harmonies on orchestral instruments, it will be necessary at some point in the compositional process to render the frequencies into musical pitches for the sake of practical playability. Since this approximation is often a last step, the musical structure can be generated in their most precise form (frequencies), then approximated to the nearest available pitch depending on the details of the instrumental abilities and context. This also allows many spectral

composers to tailor the level of difficulty to individual realizations, adding or removing difficult notes in a way that does not change the underlying structure, but merely refines or coarsens the approximation of the abstract musical structure. Since the ear analyses structures based upon their frequency structure, the ear is able to hear past these approximations and hear the underlying frequency structure whenever the approximation is within tolerable limits. Moreover, as this music has become more widely performed a whole host of performers have mastered techniques of playing 1/4 and even 1/8-tones (division of the octave into 24 or 48 equal steps, instead of the traditional 12 steps of the chromatic scale) when they are presented in coherent harmonic contexts.

Absolute Duration vs. Symbolic Rhythm

Just as frequencies offer spectral musicians a more direct access to many sonic structures than notes do, absolute temporal durations are often an easier way to conceptualize time and rhythm than the symbolic grid-subdivisions of musical notation. This continuous conception has been less widely exploited for rhythm than the equivalent one has been for frequencies, since the problem of approximation is greater and the accuracy expected from performers and perceived by listeners is much less. Therefore the domain in which durational rhythmic thinking has been widely applied is limited to macro-rhythmic relations along with a few special case relations, in which durations have great advantages. In these situations, durationally conceived relations are often more flexible than symbolic ones. An identical temporal structure can easily be stretched or compressed and can have the number of events increased or reduced without changing the framework of its overall perception, whereas this is often difficult or impossible in a traditionally notated passage without completely re-notating it or changing the tempos

(which in certain contexts may not be possible or desirable).

Computer Assisted Composition

As will be clear by this point, many of the new techniques introduced by spectral composers require calculations. These calculations are required to generate basic material (even the most basic conversions from frequencies to notes, for example, can be very time consuming when performed manually); but the calculated material is not used directly in a musical composition, rather it is manipulated musically by the composer. When these calculations represent a significant investment of time, it is difficult for composers to feel free with the material generated. They are unlikely to throw away weeks of elaborate calculation just because it is not exactly what they sought. They are more likely to perhaps tweak it a bit and then make do. Yet this freedom to experiment and to evaluate (even extremely complex) material is exactly what the spectral composers needed.

The timing was fortunate, in that computers were beginning to become prevalent and their usefulness for this application was evident. For the computer, none of these calculations were of significant complexity and, thus, with the proper environment a composer could work freely and intuitively with a material of almost any complexity. Tristan Murail and others (including the author) began to collaborate on a series of programs with the French institute IRCAM on more generalized environments for musical calculation, manipulation, modeling and analysis. The two principal environments currently in use are OpenMusic and AudioSculpt.

After-Effects

In his last article before an untimely death, Gérard Grisey presented what he saw as the notable consequences that the developments of spectral music had had on "more than just orthodox spectral composers [. . .]" (Grisey 2000, pp. 2-3).

Harmonic and timbral consequences:

- More 'ecological' approach to timbres, noises and intervals.
- Integration of harmony and timbre within a single entity.
- Integration of all sounds (from white noise to sinusoidal sounds).
- Creation of new harmonic functions which include the notions of complementarity (acoustic, not chromatic) and hierarchies of complexity.
- Re-establishment, within a broader context, of the ideas of consonance and dissonance as well as modulations.
- Breaking out from the tempered system.
- Establishing new scales and—over time—a melodic re-invention.

Temporal consequences:

- More attentive attitude towards the phenomenology of perception.
- Integration of time as the very object of form.
- Exploration of 'stretched' time and 'contracted' time, separate from that of the rhythms of language.
- Renovation—over time—of a supple metric and the exploration of the thresholds between rhythms and durations.

- Possible dialectics between musics evolving in radically different times.

Formal consequences:

- More ‘organic’ approach to form by self-generation of sounds.
- Exploration of all forms of fusion and the thresholds between different parameters.
- Potential for interplay between fusion and continuity, on one side, and diffraction and discontinuity, on the other.
- Invention of processes, as opposed to traditional development.
- Use of supple, neutral sonic archetypes which facilitate the perception and memorization of processes.
- Superposing and placing in and out of phase contradictory, partial, or implied processes.
- Superposition and juxtaposition of forms flowing within radically different time-frames.

This list should begin to put into perspective just how radical the shift caused by the innovations of Grisey, Murail and the other who followed them was. Composers from the most combinatorially complex to the most expressively Romantic now all routinely speak about sound and how it affects their thinking (something that was unheard of 20 years ago). Spectral techniques have fundamentally altered the terms of the debate, even for those who reject the music utterly. While there are certainly other factors in this transformation, the leadership and innovation of the spectral movement clearly played a

central role in redefining the relationship between musical structures and sound.

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