SPACE, SOUND, AND THE DIGITAL ORGAN

by

ALEXANDER BEAN

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The digital organ is a unique instrument. The acoustic pipe organ is fixed in one location with a limited number of of stops available to the organist. In contrast, the digital organ is mobile and, when used in combination with a computer, offers the organist an infinite array of different sounds. Unfortunately, composers and performers have hitherto ignored the unique capabilities of the digital organ. This paper explores the history of the pipe organ leading to the development of the digital organ. In addition, this paper presents a new composition created specifically for digital organ, entitled *Spatia*. In my composition, I explore the possibilities of composing specifically for digital organ. I have designed a unique set of nine organ stops for each specific performance venue and date. Six of these stops feature sounds that are recorded from the performance space and its surrounding locale. The three other stops feature the sound of the full organ altered to varying degrees by the resonant frequencies of the performance space (i.e. those pitches which sound clearest in a particular room). One stop features the unaltered full organ sound, one stop features the full organ sound distorted by the resonant frequencies, and the final stop features the resonant frequencies without the full organ sound. These basic materials are formed into a musical composition through the use of two motives and two musical transformations. *Spatia* represents a wholly new form of composition with profound implications for the future of digital organ music.

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Chapter 1: Introduction

The organ may be generally defined as an instrument with four parts: 1) a bellows that drives pressurized air into 2) a wind chest that stores air until it is admitted by 3) a keyboard mechanism into 4) one or more ranks of pipes. This definition may be supplemented with three additions, so as to completely describe the modern instrument. The pipe organ has 5) pedals which play notes similar to the manuals played with the hands; and 6) has multiple ranks of varying tone colors, which are divided into stops, and which may be controlled individually by the use of a mechanism such as drawbars, drawknobs, or tabs. A final characteristic that is found on most (but not all) modern instruments is 7) the swell pedal, which allows for the volume of collections of pipes to be gradually and smoothly increased or decreased.[1] All organs throughout the instrument's 2000-year history have been constructed with the first four characteristics, and the prevailing building style has included the final three capabilities for at least 300 years. Organs with pedals and numerous stops have become so ubiquitous that an organ without them would scarcely be considered an organ at all.

If a pipe organ is defined with the seven parts listed above, how should the digital organ be defined? The digital organ has no bellows, wind chest, or pipes. And while digital organs are, like the pipe organ, built with stop controls, keyboards, pedalboards, and expression pedals, these mechanisms control elements of a computer program rather than mechanical components. However, the concept of registration (the synthesis of a new sounds by the combination of individual stops) is identical on both the digital organ and the pipe organ. Thus, while the digital organ lacks all of the

[1] The four-part definition appears in several sources including Williams (1980) and Sumner (1981), to which I have added three additional characteristics.

mechanisms required for sound production in the pipe organ, the digital organ is still an "organ" inasmuch as an organist must use the same practice of registration on both instruments. Yet, because the digital organ produces sound with computers rather than with pipes, the instrument can produce timbres that are impossible to produce with mechanical means. Unfortunately, contemporary composers are not creating works specifically for the digital organ, and organists (with the sole exception of Cameron Carpenter and his International Touring Organ)[2] are generally ambivalent towards the instrument. This is a tremendous mistake. The digital organ has the capacity to expand its repertoire of sounds beyond the more conventional sounds of the acoustic organ. Why have composers, performers, or builders not yet taken advantage of this capability?

As a double major in Organ Performance and Composition, these questions greatly interest me. For my Honors College thesis, I will compose a piece of music utilizing the capacity of the digital organ to include sounds—in this case recorded "sound samples"—not found in acoustic pipe organs. I will also explore the issue of site-specificity. As mentioned above, each concert pipe organ is built for a single particular venue, while digital organs are portable and may be played in a variety of different locations. In general, works specifically for digital organ are in general not site-specific, but may be performed in a variety of acoustic environments. However, I find the site-specificity of the pipe organ to be an essential part of its character, which is not characteristic of the digital organ. In order to make the digital organ site-specific in my composition, I will use sound samples recorded in the space wherein the piece will

[2] Cameron Carpenter, "Vision," http://www.cameroncarpenter.com/touring-organ/vision/.

be performed. Each performance in each new location will use a different set of samples, and thus will sound totally distinct. In this way, I transform the digital organ into a site-specific instrument in the context of my composition.

Chapter 2: History of the Organ

It must be noted that the history of the organ presented in this paper is deliberately limited and incomplete. My principal aim in this thesis project is the creation of a new musical work for the digital organ. I include a history of the instrument only as a means of situating my piece within the historical context of the instrument. Thus, it is neither necessary nor desirable to present the entire 2000-year history of the organ in great detail. Rather, I will focus on examples of the specific ways composers interacted with the tonal and mechanical capabilities of the instruments that were available to them. Accordingly, I divide the history of the organ into seven parts: 1) invention and early forms; 2) Italian Renaissance and Baroque; 3) English Baroque; 4) French Classic; 5) German Baroque; 6) French Romantic and the symphonic organ; and 7) the digital organ. These examples of organ building and composition were chosen because each case presents a specific technical development and a body of repertoire that incorporates that development. In addition, these technical features are still found on modern pipe organs, and these repertoires are still played by contemporary organists. It is for this reason that the Spanish and Dutch organs are not discussed. Spanish organ builders invented a number of new stops, including percussion sounds, but almost none of these features have been reproduced on modern instruments. And while Dutch organ building styles were highly influential in both France and Germany, the repertoire produced by Dutch composers is no longer widely performed (with the sole exception of the works of J. P. Sweelinck).

Invention and Early Forms

The first instances of the word *organon* (ὄργανον) refer not to a musical instrument, but to a tool or "instrument" with which one does work or *ergon* (ἔργον). When the organ was first invented, ostensibly by Ctesibius (Ktesibios) of Alexandria, it was viewed not as a musical instrument, but as another member of a family of mechanical contrivances driven by water or air pressure. The first organ was termed the *hydraulis* or hydraulic organ (ὄργανον ὑραυλικόν) as it used water to hold and regulate air pressure.[3] More precisely, air was driven into the machine by a lever connected to a piston inside a cylinder. On the downward stroke, air would be drawn into the piston chamber through an inlet valve. On the upward stroke, the piston would compress the air, which caused the inlet valve to close and forced air into a hemispherical chamber called the *pnigeus* (πνιγεύσ), which was itself held in a cistern containing water. The pressurized air would force water out through holes in the bottom of the *pnigeus*, thus raising the water level in the cistern. The weight of the water would in turn force air from the *pnigeus* and into the chest holding the pipes. In addition, the water would maintain pressure in the *pnigeus* even while the piston was withdrawn for the next stroke. The pipes of the *hydraulis* were separated from the wind chest by a perforated strip of wood running between the top of the wind chest and the foot of the pipes. When a key was depressed, the strip slid such that the hole in the strip lines up with the foot of the pipe, allowing air to flow through the pipe, causing it to speak. When the key was

[3] William Leslie Sumner, *The Organ: Its Evolution, Principles of Construction and Use*, Fourth ed. (New York: St. Martin's Press, 1981).

released, the spring made of horn or iron would pull the strip back into place, obstructing the flow of air.[4]

Very little is known about the *hydraulis* beyond the mechanics of sound production. Inscriptions and iconography indicate that the organ was used in gladiatorial contests, though it can only be speculated as to how or when it was performed. It is known that the organ was used at the more important theaters, events, circuses, and banquets by the second century A.D. at latest, and was used in this capacity at least until the fourth century. However, it is unknown whether the organ was played for prelude, postlude, marking significant moments in an entertainment or ceremony, or merely served as a call to attendance.

Similarly, very little is known for certain about the sound of the *hydraulis*. Modern reconstructions of the hydraulic organ suggest they had wind pressures between 7.5 and 30 cm. This would make the volume of the *hydraulis* either equal to the volume of most modern pipe organ stops, or somewhat greater than the typical stop on the modern pipe organ. However, it is not known what type of pipe was used on the *hydraulis* (were reeds included on the instrument?) or whether the diameter of the pipes was constant (which would effect the tone). It is not even known how many octaves the keyboard spanned, or whether multiple ranks could be played simultaneously. The design of a small organ discovered at Aquincum, Hungary indicates that some Roman organs had multiple ranks of pipes, though it is thought that the four ranks of the

[4] Peter Williams, *A New History of the Organ from the Greeks to the Present Day* (London: Indiana University Press, 1980).

Aquincum organ were used to play four different modes or *tonoi*, did not play different tone colors, and were never played together.[5]

The *hydraulis* disappeared from the historical record in the Western Roman Empire sometime in the 5th or 6th century, though it was still used in the Byzantine Empire and in the nascent Arab nations. At some point during the late Roman and Byzantine eras, the complicated piston and cistern system of the *hydraulis* was replaced with a bellows mechanism. The organ was slowly reintroduced in the West with the diplomatic gift of an organ from the Byzantine Emperor to Pepin, King of the Franks, in 757. However, it was not until the 10th century that the organ became prominent in the West, when it began to be used as a church instrument. [6]

Documentation from the 11th century (specifically the anonymous Berne Codex and the encyclopedia of Theophilus) describes an instrument with several improvements on the Greco-Roman instrument of the preceding millennium. Similar to the keyboard of the *hydraulis*, each key was set on a pivot and connected to a perforated wooden slider, which would move backwards when the key was depressed in order to align the hole in the slider with the channel to the pipes, thus allowing in air from the wind chest. Theophilus and the Berne Codex describe two different systems for sounding multiple ranks of pipes. In the system of Theophilus, multiple ranks of pipes share a single wind channel. Thus the slider would need only a single hole to admit air from the wind chest. In contrast, in the Berne organ, each rank of pipes has a separate channel, and so the key slider would need to be perforated in multiple positions to allow air into each rank of

[5] Ibid.
[6] Ibid.

pipes. Regardless of the specifics, both sources describe systems with multiple ranks of pipes that could not be played independently.[7]

Over the next 400 years, the role of the organ in the Western church was gradually increased and standardized, such that it became a standard part of liturgical practice in all but the most conservative churches and monasteries.[8] By the end of the 13th century, the use of other instruments was banned, and the pratice of *alternatim*, where the organist would play an embellished response to a sung line of text, became common.[9] It was also at this time that organ builders began to add significantly more ranks to the organ. As noted above, these ranks could not be played independently but could only be used as a group, which was termed the *blockwerk*. Later sources, such as the 1619 *Syntagma musicum* of Praetorius, indicate that organs were constructed with multiple keyboards, each controlling either a separate collection of pipes or a specific portion of the *blockwerk*. In this system, the organist playing a four-manual instrument would only have access to four different tone colors and levels of volume. Moreover, this design was fixed during the organ's construction, and could not be changed unless the entire instrument was dissembled and rebuilt. Late 14th sources seem to indicate the development of primitive stop-controls, but the mechanisms are not described in detail, and any claim about the existence of stops at such an early date is little more than pure conjecture.[10]

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[7] Ibid.
[8] In particular, the Cistercian and Carthusian monastic orders banned the use of instruments (including the organ) within the liturgy.
[9] Williams, *A New History of the Organ from the Greeks to the Present Day*.
[10] Ibid.

There were two significant changes in organ building that took place beginning in the mid-15th century. First, three competing mechanisms were developed for separating the *blockwerk*. Some builders elected to place groups of pipes on separate wind chests. The supply of wind to each wind chest could be shut off independently by use of a valve somewhere between the bellows and the pallet-box. Typically, the organ would be divided only once to allow the lower ranks of the *blockwerk* to be played independently of the higher ranks. As this system could produce only one or two changes in timbre, builders developed alternative systems of stop controls. The form that is still used today is the slider chest system. In this design, a draw bar would control a strip of perforated wood that ran along the entire length of a rank of pipes. When the stop is drawn, the strip moves to align the holes with the feet of the pipes, thereby allowing air to flow from the wind chest into the pipes.[11] Another significant change is the advent of tracker action. In this design, the keys of the organ were not connected to sliders (as in the action of the *hydraulis*) but were instead connected to a spring-loaded pallet by a series of strings or leather cords. The pallet sealed a narrow channel between the wind chest and the pipes, and thus prevented air from reaching the pipes. When a key is depressed, the pallet is in turn depressed, which allows air to pass from the wind chest into the pipes. This invention allowed builders to add more pipes to the organ and to place them further away from the keyboard. Prior to this development, builders could only place pipes immediately behind the keyboard, as the slider action required the keys and the pipes they controlled to be aligned.[12]

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[11] Sumner, *The Organ: Its Evolution, Principles of Construction and Use*.
[12] Williams, *A New History of the Organ from the Greeks to the Present Day*.

Italian Baroque

These changes in building practice occurred throughout Europe, but became most common in Italy and the Netherlands earlier than in any other region. Italian composers and performers are particularly significant in that they developed registration instructions for particular types of pieces before composers in any other region. The organ built in the Cathedral of Milan in 1508 by Leonardo da Salisburgo exemplifies the Italian organ style, and had the following specification:[13]

Italian name:	**English Equivalent:**
Tenore	Principal 8'
Octava	Octave 4'
Duodecima	Quint 2⅔'
Quintadecima	Octave 2'
Decima nona	Quint 1⅓'
Vigesima seconda	Octave 1'
Vigesima sesta	Quint ⅔'
Vigesima nona	Octave ½'

Table 1: Stop-list of the 1508 organ in the Cathedral of Milan.

The above chart exhibits two characteristics of Italian organs even into the late 18th century. First, Italian stop-names are derived from the interval they form with the lowest stop on the organ. Thus, if lowest stop on the organ is the 8' principal, then the 4' principal stop would be named "Octava", as it forms an octave with the 8' principal.

[13] ed. Calvert Johnson, *Italy: 1550-1660*, ed. Wayne Leupold, vol. 6, Historical Organ Techniques and Performance: An Historical Survey of Organ Performance Practices and Repertoire (USA: Wayne Leupold, Inc., 2002).

The principal 2⅔' (normally called the Quint in English) would be called the "Duodecima" as it forms the interval of a 12th (an octave and a fifth) with the principal 8'. The other principal characteristic of the Italian organ building style is the large number of separate principal ranks.[14] All other organ-building styles group the highest ranks of principals (usually the 1⅓', 1', ⅔', and ½' ranks) into a single stop called the "mixture".[15] The Italian organ could produce a wider range of principal timbres than its counterparts in other parts of Europe, but required more stop controls. In addition, the pipes of the principal chorus were constructed with a narrower diameter than was used on organs anywhere else in Europe. This gave the instrument a round, sweet, silvery, "vocal" tone.[16]

By the middle of the 16th century, Italian organ builders were constructing instruments with two additional timbres, in addition to the standard principal chorus. The Brescia Cathedral, built in 1536 by Gian Giacomo Antegnati, includes two flute stops at the 8' and 4' pitch levels. The organ at the church of San Giuseppe in Brescia, built in 1581 by Graziadio and Constanzo Antegnati, includes the "Fiffaro" stop (also named the "voce umana"). This stop was a principal stop tuned sharp in order to produce a subtle undulation when played with the ordinary principal stop.[17]

Italian organ music was especially vocal in character, with contrapuntal lines moving primarily in stepwise motion. Indeed, many of the pieces in the three mass settings of *Fiori Musicali* by Giralamo Frescobaldi appear similar to the sacred choral

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[14] Ibid.
[15] Williams, *A New History of the Organ from the Greeks to the Present Day*.
[16] Poul-Gerhard Andersen, *Organ Building and Design*, trans. Joanne Curnutt (London: George Allen and Unwin LTD, 1969).
[17] Calvert Johnson, *Italy: 1550-1660*, 6.

music of Claudio Monteverdi. This marked tendency for vocal-style writing was likely influenced by three phenomena. First, almost all composers of music for the organ were creating music for the Catholic Church. As an institution, the Church preferred more conservative music influenced by vocal writing and based on chant melodies. This was in stark contrast to secular harpsichord music, which had little or no vocal influence. Second, the general preference in organ music at the time was for vocal-influenced polyphony. The earliest German and French composers created organ works in similar vocal style to the works composed by Italians. Finally, the construction of the pipes of an Italian organ created a more vocal timbre than was produced on organs anywhere else in Europe. Whether this drove composers to create vocal-influenced polyphony on the organ, or was the result of builders creating organs for composers already writing vocal polyphony cannot be definitely determined.

Composers in Italy also responded directly to building practices by providing extensive registration instructions, which detailed the stops one should use on a particular type and character of piece. The instructions are especially significant because they show the precision with which composers treated the resources of the Italian organ. These instructions are organized either by musical mode (as in *Il Transilvano* by Diruta) or by type of piece and function within the church service (as in instructions left by Banchieri, Diruta, Monteverdi, and Ghizzolo). In providing registration instructions by mode, Diruta considers the affect ascribed to each mode. Pieces in bright, sweet, pleasing, or joyful modes were registered with brighter stops (usually including the higher principal ranks), while sorrowful, devout, or serious modes were registered with darker stops (usually without the higher principal ranks, and often with the flutes and tremolo). Similarly, registration instructions listed by type of piece accounted for the character of the piece, but also considered the function with the liturgy. Pieces at the beginning of a service (such as preludes or toccatas) or at the end (such as the *Deo Gracias*) were to be registered with the *ripieno*, or full principal chorus. Pieces at prayerful or introspective moments in the service, such as Elevations (played immediately after the consecration of the Eucharist), Graduals, or at the *Crucifixus* of the Credo were to be played with quiet registrations. Usually this was a single Principal 8' or Flute 4' stop, along with the tremolo or the *Voce umana* to soften and thicken the sound. The specificity of these instructions demonstrates that composers created music with the specific sound of the Italian organ in mind.[18]

The Classical French Organ

The earliest examples of the organ in France are virtually indistinguishable from the Italian organ, and were built primarily in the south of France. The 1510 organ constructed in the Bordeaux Church of Saint-Michel is a prime example of this building style. This organ had seven separate principal ranks from 16' to 1' (similar to the Italian instrument described above), in addition to Flute 8' and Flute 4' ranks.[19] From 1530 to 1630, the French style of organ playing and registration were almost indistinguishable from its Italian counterpart. The music of Jean Titelouze (1562/63-1633) is remarkably similarly to the music of Giralamo Frescobaldi: both are mostly based on chant melodies, and both feature vocal-influenced polyphony.[20] The specifications of these

[18] Ibid.
[19] Fenner Douglass, *The Language of the Classical French Organ: A Musical Tradition before 1800* (New Haven: Yale University Press, 1995).
[20] Corliss Richard Arnold, *Organ Literature: A Comprehensive Survey* (Scarecrow Press, 1973).

organs suggest that French registration practice was similar to Italian registration practice, but as few French instruction manuals from this period still exist, it is difficult to make any claim about the sound of their organ music. What is known is that throughout the 16th Century French builders increasingly followed the style of Dutch and North German builders (discussed below) and collected the highest principal ranks into mixture stops and added colorful stops, such as the *krummhorn*, and the *vox huamine*. By 1650, the French style of organ building had become entirely differentiated from the Italian style.[21]

The Classical French organ style encompassed a model of organ design, composition, and registration that was remarkably uniform across the entirety of France (especially when compared to the national styles of Germany, England, and Italy). The following specification for the Paris Chapelle de L'Ecole Militaire, built in 1772, is characteristic of most organs during the French Classical period:[22]

Grand Orgue 51 keys		
8' Montre	8' Dessus de flûte allemande, 30 pipes	8' Trompette
8' Bourdon	2⅔' Nazard	4' Clairon
4' Prestant	2' Quarte de Nazard	8' Basson/Voix humaine allemande
2' Doublette	1⅗' Tierce	
IV Fourniture[23]	V Cornet	

[21] Douglass, *The Language of the Classical French Organ: A Musical Tradition before 1800*.
[22] Ibid.

IV Cymbale[23]		
Récit		
	V Cornet	8’ Trompette
Positif		
8’ Bourdon	8’ Dessus	8’ Cromorne
4’ Prestant	2⅔’ Nazard	8’ Hautbois
2’ Doublette	1⅗’ Tierce	
III Fourniture[23]	1⅓’ Larigot	
III Cymbale[23]		
Pédale, 34 keys (F to D)		
	8’ Flûte, 27 pipes	8’ Trompette, 34 pipes
	4’ Flûte, 27 pipes	4’ Clairon, 34 pipes
2 tremblants (tremulants) , one strong and one weak		

Table 2: Specification of the 1772 organ at the Paris Chapelle de L’Ecole Militaire.

This design has several unique and noteworthy features. First, all three manuals have a tierce or cornet, which can either be drawn from a single stop or composed from multiple stops. If composed from multiple stops, one must pull the 8’, 4’, 2⅔’, 2’, and

[23] The Cymbale and Fourniture are both mixtures composed of high-pitched principal ranks. The Cymbale contains higher-pithced ranks than the Fourniture and is designed to complement the Fourniture when the two stops are used together in the *plein jeu*. In addition, the term “Fourniture” appears earlier as the French equivalent of the German “*blockwerk*”. This indicates that the Cymbale was designed at a later date specifically to complement the Fourniture in various registrations. The 18th Century French organ builder Dom Bedos also notes that the Fourniture will have at least as many ranks as the Cymbale, if not more.

1⅗’ stops. These fives ranks of pipes can also be drawn from a single stop labeled V Cornet. In either case, the resultant sound is very colorful, and is composed of the following harmonics: the fundamental pitch, the octave, the octave and a fifth, two octaves, and two octaves and a major third. This color is one of the principal solo sounds used in French organ music, and its inclusion on three independent manuals allows for dialogues between subtly distinct versions of the same timbre. In addition to the cornet sound, both the Positif and the Grand Orgue have a *plein jeu* (the French term for the full principal chorus). On the Grand Orgue, this is composed of the 8’ Montre, 8’ Bourdon, 4’ Prestant, 2’ Doublette, the Fourniture, and the Cymbale. On the Positif, the *plein jeu* is composed of the 8’ Bourdon, the 4’ Prestant, the 2’ Doublette, the Fourniture, and the Cymbale. Often, the *plein jeu* would also contain a 16’ Montre or Bourdon in the Grand Orgue. The reeds on the different manuals serve various distinct purposes. The 8’ Trompette on the Grand Orgue can be used either as a solo sound or as a component of the *grand jeu* (a type of full organ sound using the reed ranks but not the mixtures). In contrast, the 8’ Basson was used exclusively as a solo stop, while the 4’ Clairon was used exclusively as part of the *grand jeu*. The Trompette on the Récit, and the Cromorne and Hautbois on the Positif were all used exclusively as solo sounds. The various stops on the Pédale were used infrequently. The reeds were used most often to play a *cantus firmus* line of chant, while the flute ranks were used in soft, delicate textures.[24]

As in Italy, French composers created organ music specifically for use in the Catholic liturgy. Most organ pieces were composed as versets, short pieces intended to

[24] Douglass, *The Language of the Classical French Organ: A Musical Tradition before 1800*.

be played in alternation with a choir singing portions of the liturgy. Organ masses were collections of these short pieces, organized according to their function in the liturgy. Occasionally these versets were published not as organ masses, but as "organ books" (*Livres d'Orgue*). In this case, the pieces would be organized by musical mode rather than liturgical function.[25]

Similar to the Italians, French composers and organ builders provided extensive registration instructions. Unlike in Italy, French composers also provided titles that indicated the registration that should be used in a given piece. Thus, French registration markings were far more specific than Italian markings, which were never indicated on the music itself. In addition, the French provided far more detailed registration instructions generally. This is likely due to the French predilection for colorful music, as well as to the design of the French organ, which had many more stops (and many more kinds of stops) than did the Italian organ.

The various registrations can mostly be grouped into four categories based on musical texture: 1) broad textures, 2) contrapuntal textures, 3) melodic textures, and 4) composite textures (which are combinations of the first three textures).[26] The registrations grouped under the broad textures include the *plein jeu*, the *grand jeu*, the *fugue*, and the *fond d'orgue*. The *plein jeu*, as discussed, used the full principal chorus. The first piece in a set would always be played on the *plein jeu*, and often the final piece in a set would as well. Pieces with this registration would always incorporate a cantus firmus chant line, often played on the 8' Trompette in the Pédale. The *grand jeu* was always used on the *Offertoire*, a large piece in the middle of the mass that would be

[25] Arnold, *Organ Literature: A Comprehensive Survey*.
[26] This terminology is taken from Douglass (1995).

played as the Eucharist is brought forward to be placed on the altar. A fugue would always be played after the opening *plein jeu*, and would always be played on a reed stop (either the Trompette or the Cromorne). Unlike the German fugue, the French fugue is barely contrapuntal, with the only true counterpoint appearing in the initial three or four entrances of the subject and its answer. Instead, the French fugue was intended to show off the brilliance of the reed stop. Finally the *fond d'orgue* was played on the 16', 8', and 4' principals and flutes. All of these registrations share a similar character, tempo, and texture. All of these pieces were played in a slow to moderate tempo with a majestic character. Also, all of these pieces were composed in a mostly homophonic texture with imitative ornamentations, and with a fairly slow harmonic rhythm. [27]

The registrations used in contrapuntal textures could vary extensively in tempo, character, and color. Often these pieces would be light and in a compound meter, but this was by no means the rule. However, pieces composed in a contrapuntal texture always used Duo, Trio, or Quatour (quartet) textures of at least two distinct timbres. One voice of the texture would always be a Cornet or Tierce; the other voice would often be a reed (either the Trompette or the Cromorne). The pedal (which was only used in a Trio or Quattour) would always be played with a flute stop. The final group of registrations, those with melodic textures, is as heterogeneous as those of contrapuntal texture. This group includes the lyric Tierce en Taille and the lively Basse de Trompette.[28]

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[27] Douglass, *The Language of the Classical French Organ: A Musical Tradition before 1800*.
[28] Ibid.

The English[29] Organ

The history of organ building and composition in England is easily the most tumultuous in Europe. Many of the earliest written accounts of organs describe instruments in use in England, including the somewhat fanciful 993-994 account by the monk Wulfstan at Winchester Cathedral. The first collection of music composed specifically for a keyboard instrument was discovered in Robertsbridge, Sussex, and dates from 1360. Very little can be definitively proven about the English organ before 1600. Four organ contracts survive in fragmentary form, three that describe the construction of a new organ at the church of All Hallows Barking in 1519-1521, and a fourth that describes a new organ constructed at the Holy Trinity church in Coventry dated 1526. In addition, there are fragments of two different organs that have been discovered in Wetheringsett, Sussex, which has been dated to around 1520, and at Wingfield, Suffolk, which cannot not be accurately dated. Finally, there was an instrument in Tong, Shropshire (now destroyed) that was described in general terms in 1789.[30]

These five sources provide only a few details about the early English organ. All five instruments had only a single manual and no pedals. The Barking and Coventry organs evidently had keyboards starting with C (i.e. the pitch two octaves below middle c'). Both organs also had twenty-seven natural keys, and thus had a compass from C to

[29] This thesis will focus strictly on the organ in the country of England. While the country of Wales was controlled by England from the 13th century, and formally united with the Kingdom of England in the 16th century, the main hub of organ building remained in England proper. Similarly, organ building and performance remained concentrated in England despite the Tudor conquest of Ireland and the Jacobean personal union and Georgian political union of England and Scotland. Thus, it is most appropriate to use the term "English Organ" despite the changing political circumstances of the British Isles and Ireland.
[30] Stephen Bicknell, *The History of the English Organ* (Cambridge: Cambridge University Press, 1996).

a’’. While the Barking organ had no accidental keys, the Coventry organ was apparently fully chromatic with nineteen accidental keys.[31]

The Barking documents indicates the longest pipe to be about 10 feet long. This would give a pitch standard roughly equivalent to a modern G or G#, rather than the far more typical C. The stop-list can be speculatively reconstructed only for the Wetheringsett and Wingfield instruments, based on the design of the respective soundboards. The Wetheringsett stop-list is reproduced below:[32]

Slide (probably connected to a draw knob)	Stop	Remarks
1 (front)	? unison (open wood)	Large foot holes suggest wooden pipes
2	Principal	
3	Principal	Pipes 4-33 grooved to façade
4	Octave	
5	Octave	
6	Superoctave	
7	Superoctave	Holes pricked through, but pipes never installed
8	Diapason (i.e. suboctave) (open wood?)	Lowest 19 notes only, large foot holes suggest wooden pipes

Table 3: Reconstructed specification of early 16th century organ found at Wetheringsett, Sussex, England.

[31] Ibid.
[32] Ibid.

The apparent lack of instruments built between 1520 and 1600 is likely due to the chaos of the English Reformation. Between 1536 and 1541, Henry VIII disbanded the Catholic monasteries in England and appropriated their property. Not only was the Church a wealthy patron of the arts and music, but the monastic houses also provided intellectual and economic support for craftsmen (including organ-builders). During the subsequent reign of Edward VI, the radical Protestant faction became ascendant, and the use of the organ in worship was frowned upon as being too Catholic. The religious persecutions of the Catholic Mary I and the excommunication of her Protestant successor Elizabeth I prompted a wave of anti-organ sentiment, which resulted in the sale or destruction of many church organs across England. The organ was preserved only in the Chapel Royal, which was under direct royal control.[33]

Opinions of the organ began to change after the accession of James I to the throne of England. James was ardently opposed to the Puritan movement, and supported the rise of the high church movement, which endeavored to reintroduce elaborate ritual and musical performance into the liturgy. Organs built in this period are largely similar to those built in the Tudor period: all but the smallest instruments have double ranks of principals, diapasons, superoctaves, and all instruments are based on a 5' or 10' pitch, rather than 8' that largely prevailed in continental Europe. There are two innovations that differentiate the 17th century organ from that of the Tudors. First, stops were designed that imitated the sound of the flute or recorder. Second, an additional manual

[33] Ibid.

was added to the organ, which controlled an additional set of pipes placed at the organist's back and directed outward into the performance space.[34]

Very little can be said with certainty about the music of the period. The organ was certainly used as accompaniment and response to the choir during the course of liturgy. Solo organ pieces were also played at the beginning and end of the service (as in modern practice), and at the Offertory. Beyond these facts, little is known. The largest collection of keyboard music from this period, the *Fitzwilliam Virginal Book*, contains both sacred and secular music, and does not differentiate between music composed for the organ and music composed for other keyboard instruments (such as the harpsichord or virginal). Needless to say, registration is not specified for any of these pieces.[35]

The Jacobean revival in organ building and composition was undone by the English Civil War and Commonwealth of 1642-1660. During this period, numerous organs were dismantled or destroyed by the Parliamentary military and, later, the Puritan government of Oliver Cromwell. When Charles II returned from France during the Restoration, French styles of organ building were introduced into England. More stops were adding to the organ, including mutations (such as the 2⅔' Nazard, which was called in English a "Nazien" "Nasone" or "Twelfth"), mixtures (such as the Cymbale and Fourniture, which became in English the "Simbale" and "Furnitor" respectively), and reeds (such as the Trumpet and Clairon, which were rendered as "Trumpett" and "Cleron"). The pitch standard also began to change during this period,

[34] Ibid.
[35] Ibid.

with at least one organ seeming to be constructed with both a mix of a 12’ and 8’ pitch standard.[36]

The installation of William of Orange as King of England, Ireland, and Scotland during the Glorious Revolution introduced Northern European organ building styles into England. In particular, the Dutch-English builder Bernard Smith (Baerant Smitt) was particularly influential in building new instruments after the turbulence of the English Civil War. Characteristics of Smith’s instruments (as well as those of his contemporary and competitor, Renatus Harris) include three manuals of roughly equal size, a number of different colors of flute stops, a sizable collection of reeds, and a number of mixtures. This style of instrument differed from that of the French in that it lacked the large number of independent mutations of the French organ, particularly the 1⅗’ and the 1⅓’. In addition, this style of organ included early forms of string stops, which were designed to imitate the sound of string instruments such as the violin or viola da gamba. However, these English organs differed from organs in Northern Europe in their tone, which was sweeter than that of the Northern European organ, and the total lack of a pedalboard.[37]

During the Georgian period, which began with the ascent of George I to the throne, there were two innovations that were immensely significant for the course of organ development. The first was the invention of a mechanism that allowed the stops of one manual to be played on another. This provided the organist with a greater range of tonal possibilities, as the stops from one manual could be combined with those from another without needing to play both manuals simultaneously by coupling them

[36] Ibid.
[37] Ibid.

together. The second innovation was the Swell box. The earliest surviving form of this mechanism was a wooden box with a sliding sash front operated by a pedal which returned under gravity to the closed position when released. This system required the organist to constantly hold the swell pedal at a particular level in order to attain a constant volume. If the organist did not hold the swell pedal, the swell box would fall closed. This was obviously undesirable, and gradually the vertical-closing model of the swell box gave way to the horizontal-closing box, wherein the shutters would remain in the same position unless changed by the organist.[38]

The German Baroque Organ

As discussed above, the organ building styles of Central and North Germany were wholly a development of the building practices in the Netherlands.[39] Most important among these building practices is the *Werkprinzip* design. Organs built according to the *Werkprinzip* had pipes placed in discrete groups in distinct positions in and around the organ. For example, the English "Chair Organ" was a borrowing of the equivalent Dutch "Rugpositief" division ("Rückpositiv" in German). In addition to the main pipes of the instrument (called the "Hoofdwerk" or "Hauptwerk") and the pipes placed at the organists back, there were three other commonly built divisions: 1) pipes could be placed near the top of the organ, and the division would be called the "Bovenwerk" or "Oberwerk"; 2) pipes could be placed directly in front of the organist at chest or head level, and the division would be called the "Borstwerk" or "Brustwerk";

[38] Ibid.

[39] The term "Netherlands" here refers to the Dutch-speaking areas of the Low Countries, which today comprise the Kingdom of the Netherlands and the Flanders region of Belgium.

3) pipes for the pedal division (which was called the "Pedaal" or "Pedal") were placed in separate groups to the left and right of the main body of the organ.[40]

In contrast to the French style of organ building, the divisions of the Northern European organ were roughly equal in terms of number of pipes. While the French *Récit* division included only one or two ranks of pipes, a small German *Brustwerk* would have at least four ranks, and it would not be uncommon for the *Brustwerk* to include as many as six or seven ranks. In addition, the divisions of the French organ were standardized according to colors required on each manual. For example, both the *Grand Orgue* and *Positif* included a *plein jeu*, a *cornet* (whether as separable stops or as a single inseparable five-rank stop), and at least two reeds (typically a trumpet and a solo reed). In contrast, the Northern European organ never had a standardized stop-list. The *Hauptwerk* would always include a full principal chorus (called the *plenum*) and usually would also include at least one 8' flute and an 8' trumpet rank. The *Oberwerk* or *Rückpositiv*[41] would always include a full chorus of flutes (8', 4', 2', and a mixture), and would usually include the stops required for a cornet (2⅔'and 1⅗'). The *Oberwerk*/*Rückpositiv* would also include at least one additional flute rank of a different color. This stop would often be a *Quintatön*, a flute rank with a strong presence of the 2nd overtone. Finally the *Oberwerk*/*Rückpositiv* would also include one solo reed and a trumpet stop. The *Brustwerk* was always the smallest and quietest division, but would still include at least three flute stops (8', 4', and 2') and one solo reed. Finally, the pedal in the Northern European style would always include a large number of principal, reed,

[40] Andersen, *Organ Building and Design*.
[41] These two divisions do not occur together except on the largest instruments.

and flute ranks, and could equal the *Hauptwerk* in volume. The Totentanz organ in Lübeck represents a typical specification of a large Northern European Organ:[42]

Hauptwerk	**Rückpositiv**	**Brustwerk**	**Pedal**
Quintatön 16’	Principal 8’	Gedackt 8’[43]	Principal 16’
Principal 8’	Rohrflöte 8’[43]	Quintatön 4’	Subass 16’[43]
Spitzflöte 8’[43]	Octave 4’	Nachthorn 2’[43]	Octave 8’
Octave 4’	Rohrflöte 4’	Quinte 1⅓’	Gedackt 8’[43]
Nasat 2⅔’	Flöte 1⅓’	Nachthorn 1’[43]	Octave 4’
Rauschquinte II[44]	Sesquialtera II[45]	Mixtur IV	Quintatön 4’
Mixtur VI-X	Mixtur VI-VIII	Krummhorn 8’[46]	Octave 2’
Trompete 8’	Dulzian 16’[46]	Schalmei 4’[46]	Nachthorn 1’[43]
	Trichterregal 8’[46]		Mixtur IV
			Zimbel II
			Posaune 16’
			Dulzian 16’[46]
			Trompete 8’
			Schalmei 4’[46]
			Cornett 2’

Table 4: Stop-list of the Totentanz organ in Lübeck, Germany.

[42] Andersen, *Organ Building and Design*.
[43] “Rohrflöte”, “Spitzflöte”, “Gedackt”, “Subass”, and “Nachthorn” are names for different colors of flute. “Subass” is used exclusively for a 16’ or 32’ stop, and “Nachthorn” is used primarily for a 4’ stop or higher.
[44] The “Rauschquinte” is a small mixture of two ranks that sound a fourth apart, either at 2⅔’ and 2’ or at 1⅓’ and 1’.
[45] On this organ, the “Sesquialtera” stop provides the 2⅔’ and 1⅗’ ranks for the cornet based on the Rohrflöte 8’.
[46] “Dulzian”, “Trichterregal”, “Schalmei”, and “Krummhorn” are all names for different colors of solo reed.

The design of this instrument demonstrates the difference between the French and German concept of the organ. The French organ is first and foremost an instrument of color. As described above, the various possibilities of registration used in French Baroque organ music are associated with a particular mood and liturgical function. In this music, registration and color determine the form, character, and mood of a piece. In German Baroque music, the compositional features are decided prior to considerations of registration. While the stop-list of each division of a French Baroque organ was determined by the colors required, the stop-list of a German Baroque organ was determined by considerations of volume and physical location of the pipes. It is necessary that the divisions of a German Baroque instrument have a comparable range of color and volume, so that the performer may change the character of the sound of the organ if necessitated by the music. In fact, echo effects, which were produced by playing a passage of music on the main manual and then on the secondary manual, thus passing the sound from one location in the organ to another, were very common in the early and middle periods of the German Baroque.[47]

It is because of this emphasis on the music above registration that there is little known about the exact sound of German Baroque music. In contrast to the French and Italians, the Germans left very few performance instructions regarding tempo or registration. The composer Samuel Scheidt provides instructions on registering chorale preludes (compositions based on a chant or chorale melody) in his *Tabulatura Nova*. However, chorale preludes form only a portion of the North German organ repertoire,

[47] Andersen, *Organ Building and Design*.

and, moreover, Scheidt's instructions are of little value in registering more complex pieces that do not have a *cantus firmus*.[48]

What is known for certain is that Northern European organ builders were designing instruments with large pedal divisions long before builders elsewhere in Europe. In addition, the Northern European pedalboard included more notes than the Italian pedalboard and was easier to play than that of the French. All of these factors enabled composers to write extensive pedal parts in their music. This in turn contributed to the rise of the fugue, which is a form used almost exclusively by German composers. Indeed, the music of J. S. Bach is unplayable on an organ with the limited pedal divisions of the English, French, and Italian organs.

The Romantic Symphonic Organ

Music during the 19th century moved away from the 18th century ideals of refinement and towards a greater range of volume and color. Styles of organ building and composition were similarly effected by this trend. Organs in the 19th century were constructed with a larger number of independent ranks, a greater range of different tone colors, a larger number of manuals, and ranks voiced for higher wind pressure. In this way, builders in the 19th century (best exemplified by Aristide Cavaille-Coll) created an instrument more influenced by a symphony-orchestral concept than by a choral concept.

All of these changes would not have been possible without technical advancements made after 1800. The first and arguably most important of these advancements was the invention of the air reservoir. The concept of a reservoir that holds air fed by the bellows was not at all new; indeed, the design *hydraulis* described

[48] Arnold, *Organ Literature: A Comprehensive Survey*.

above used a cistern for the sole purpose of holding and regulating air. But when the use of the cumbersome cistern ceased in Late Antiquity, no mechanism was designed to replace it. During the Middle Ages and the Baroque, the wind supply of the organ was limited by the number of bellows and their size. Moreover, this wind pressure was variable and unstable. When one of the bellows ran out of air, the organ would briefly be low on wind pressure. The reservoir solved this problem. The bellows fed into the reservoir, which was itself essentially a large bellows. The reservoir increased and stabilized the wind pressure. This invention allowed builders to design pipes that used higher wind pressure. This both increased the volume of the pipes and changed their tone color, and this in turn allowed builders to design instruments of greater volume and with a greater range of tone colors. Furthermore, new winding systems were invented that regulated the wind pressure and eliminated the need for an assistant to pump the bellows while the instrument was in use.[49]

However, this innovation also presented a significant technical problem. While the increased wind pressure allowed for more volume and color, it also increased the force required to work the action of the instrument, which in turn required more physical exertion to play. The solution to this problem was the Barker lever. This invention (first built in 1933 by the eponymous C. S. Barker) was a variation on the standard tracker action. But while the tracker action required a physical connection from the keyboard to the mechanism of the wind chest, and thus only could only utilize the force of the organist's hand, the Barker system used two sets of trackers. The first tracker set connected the keys on the keyboard to a small wind chest. When a key was

[49] Williams, *A New History of the Organ from the Greeks to the Present Day*.

depressed, a small lever in the wind chest would open, admitting pressurized air into a small secondary bellows, which would exert force on the main tracker that operated the mechanism in the primary wind chest. When the key was released, the lever in the small wind chest would close, the pressurized air would escape through an exhaust valve at the top of the mechanism, and the bellows would immediately deflate. The tracker would return to its relaxed position, which would stop the pipe from sounding.[50]

The Digital Organ

While there were further innovations in organ design in the late 19th century (for example, the development of purely electric action), these were less revolutionary than those described above, and did not represent a fundamental change in the concept of the organ. In contrast, the digital organ was an entirely new invention that challenged the existing concept of the organ. The first predecessor to the digital organ was the Hammond organ, which began production in 1935. Strictly speaking, this instrument was neither digital nor even truly electronic. Instead, the instrument had rotating metal "tonewheels" that produced a small electric current, which could be amplified and produced from a speaker.[51][52] The first electronic organ was the Allen electronic organ, which was first produced in 1939. This instrument used oscillating electronic circuits with vacuum tubes to produce simple waveforms that were combined into the compound waveforms associated with various organ pipes. By the Allen Organ Company's own admission, this design was extremely inefficient, and required

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[50] Ibid.
[51] Popular Mechanics, "Electric Pipeless Organ Has Millions of Tones," *Popular Mechanics*1936.
[52] This configuration meant the Hammond organ was electric or electro-mechanical.

thousands of components and hundreds of vacuum tubes to produce only a few stops.[53] Moreover, from a compositional perspective, this instrument was very limiting and uninteresting. Because the Allen electronic organ produced sound by combining simple waveforms in order to produce more complicated waveforms, it was essentially an analog synthesizer. However, a performer can manipulate the simple waveforms produced by a synthesizer to produce a large range of timbres. In contrast, the Allen electronic could not be similarly manipulated, as the waveforms were available to the performer only in fixed combinations in the form of stops. In essence, the Allen electronic was a "broken" synthesizer, in the sense that it could not produce nearly the range of timbres that could be produced by a synthesizer.

The popularization of transistors in the 1950s reduced the complexity of the Allen electronic organ, but the instrument's mode of sound production remained the same.[54] In 1971, the Allen Organ Company produced the first "Computer Organ" (a.k.a. the digital organ). In contrast to earlier instruments, which used waveform synthesis for sound production, the new digital organ used "sampling".[55] In this process of sound production, recordings are made of each individual pipe on an existing organ, and these recordings are grouped into stops and assigned to various divisions. This method of sound production is similar to the method used by pipe organs. When a key is depressed on the pipe organ, a mechanism is activated which admits air into a pipe, which causes the pipe to sound until the key is released. Similarly, when a key is depressed on a digital organ, a recording of a pipe is played and continues to play until the key is

[53] Allen Organ Co., *Mds 15/25 Manual* (Macungie, PA: Allen Organ Co. , 1993).
[54] Ibid.
[55] "Allen Organ Company Museum Tour: The Digital Revolution: 1971..." Allen Organ Co., http://www.allenorgan.com/www/company/museum/dig1.html.

released. However, like the earliest synthesizer organ, the Allen instrument was (and continues to be) essentially a defective version of an existing technology. Unlike true samplers, the Allen digital organ does not allow the user to load personally customized samples. Thus, the digital organ continues to lack a crucial capability that would vastly expand the creative resources available to composers and performers.

Chapter 3: A New Work for Digital Organ, *Spatia*

Motivation and Inspiration

The digital organ could easily represent a new phase in the evolution of the organ, and could stimulate a blossoming of compositional activity. Instead, the digital organ has largely been ignored by composers, who have exclusively composed new works for the acoustic pipe organ.[56] Composers of electronic music have also created works for MIDI instruments, synthesizers, and data-driven instruments, but have never composed music for digital organ. This is not surprising, despite the tremendous advancements that have been made in digital organ technology in the past forty years. While digital organ makers have created incredible features such as the ability to re-voice the samples of individual pipes, they have only permitted the use of proprietary samples on their instruments. This decision is understandable from a business perspective; digital organ makers can sell their instruments at a higher price if they require customers to use only their proprietary samples. However, composers cannot design and use their own sounds. In its present state, the digital organ is a defective instrument, as it merely imitates the sounds and mechanisms of its acoustic predecessor. In this thesis project, I aim to rectify this situation through the creation of a new work that utilizes the unique capabilities of the digital organ.

In particular, I wish to create an instrument that is site-specific, yet customizable. The acoustic pipe organ is obviously a site-specific instrument. An organ is constructed as part of the architecture of the performance space, and no two organs

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[56] The term "acoustic pipe organ" is redundant, as all true pipe organs are acoustic and all electronic organ lack pipes. However, the term reinforces the distinction, which is important for this thesis, between pipe organs and digital organs.

are ever identical. Similarly, each performance of a particular piece on a different organ is unique, as neither the instrument nor the performance space will be the same. On the other hand, the digital organ is not site-specific. The principal advantage of the digital organ (touted by organists such as a Cameron Carpenter) is that an organist does not need to significantly alter a performance to accommodate a new instrument. Digital organ makers such as Marshall & Ogletree have created instruments that are marginally site-specific by adding the capability to re-voice the samples of individual pipes to suit a particular performance space. Nonetheless, these instruments cannot rightly be considered more than marginally site-specific. Any of the Marshall & Ogletree instruments can be moved to a new location and re-voiced for the new space. Thus, they are not linked to a particular location in any meaningful way.

Aural Concept and Sound Design

As discussed above, the pipe organ is an unusual instrument with a long and unique history. It is the only instrument with a range of dynamics and timbres that is equal to that of the orchestra in volume and color. The organ is also the only instrument that is constructed as part of the architecture of the performance space. I made use of these features of the acoustic pipe organ as design principles for the creation of a new work created specifically for the digital organ.

My thesis composition makes use of sounds sampled from the performance space, as well as the resonant frequencies[57] of the space itself. Each stop on the organ is connected to a specific recording, and there are rules that govern the design of the sound

[57] Informally, resonant frequencies are those frequencies that sound loudest and most prominently in any particular space.

of each stop. There are six stops produced by recording the ambient sounds of the performance environment. These recordings were taken at two different times and in three different locations. The choice of time is relatively unimportant, as long as one chooses times that yield comparatively distinct sound environments, which are close to the performance date. However, the rules governing the choice of recording location are stricter. One recording must be taken inside the venue itself; one must be taken outside the performance room but within the performance building (a lobby or narthex, for example); and the final recording must be taken outside the building.

These six stops have the advantage, for the purposes of my composition, that they can easily form a simple counterpoint with each other. Each recording contains several seconds of complex sound (rather than merely a single pitch). If one depresses a single key on the keyboard while two of these six stops are pulled, then two recordings will sound simultaneously. The distinct disadvantage of these six stops is that they have no pitch control: the same recording will play regardless of which key is depressed on the keyboard. Fortunately, there is a solution to this problem. If the recordings were divided into bands of frequencies, and if these bands were properly arranged, then a semblance of a full range from low to high would be created. This is the most preferable method of incorporating pitch into the sounds of the recorded samples, as it creates the least amount of distortion in the final sample.

In addition to the six stops that feature recordings of the ambient noise of the performance, there will be three additional stops that are produced from traditional organs sounds. One stop uses the full organ sound, while the other two stops use the plenum sound distorted by the resonant frequencies of the performance space. Every room has particular frequencies that sound loudest in that space. These frequencies are determined by the geometry and contents of a particular room. Any sound produced in a room will be distorted, with the resonant frequencies emphasized and all other frequencies slightly attenuated. Typically, this effect is so minute that it goes unnoticed by the average listener. However, the resonant frequencies can be sufficiently amplified to significantly distort the original sound. As stated above, if one produces a sound in a room, particular resonant frequencies will be slightly amplified. If one records this resultant sound and plays the recording into space, one will hear a sound with the resonant frequencies amplified slightly more than before. If one continues to record each resultant sound and play each recording into the same space, one will eventually hear a sound with the resonant frequencies strongly amplified, and yet it will retain something of its original character. One can also continue this process until one hears only the resonant frequencies of the space. I produced three stops through this process (which I will hereafter call the Lucier process).[58] One stop features the unaltered full organ sound, one stop consists of the resonant frequencies of the room, and a third stop features the plenum sound with the resonant frequencies strongly emphasized (though not so much as to destroy the original character of the full organ sound).

If one considers these design principles in a hypothetical performance space, one might imagine some possibilities for new sounds corresponding to the various stops on

[58] I chose the term "Lucier process" as a reference to a famous work of electronic music (which is entitled *I am sitting in a room*) that was created using this process by the composer Alvin Lucier.

a digital organ. If we use the acoustic of Emmaus Lutheran Church[59] in Eugene as an example, we would have something approximating the following:

	Day 1 (Wednesday evening)	**Day2 (Sunday Morning)**	**Stops featuring organ sounds**
Sanctuary	Location1Time1- Choir performing warmups	Location1Time2- A hymn with the congregation accompanied by the organ	Full Organ
Lobby/Sacristy	Location2Time1- Choir performing a piece with organ, the sound is interspersed with the sound of a chair creaking and of papers shuffling	Location2Time2- Incoherent conversation	½ Resonant Frequencies
Outside	Location3Time1- Wind noise and the sound of a door opening	Location3Time2- Footsteps, the sound of a train horn, some car noise	Resonant Frequencies

Table 5: Conceptual organization of stops on the digital organ for this thesis.

In order to maximize the dynamic control over the instrument, each of the nine stops can be accessed on each of the Pedal, Great, and Swell divisions. The table below

[59] I use Emmaus Lutheran Church as an example because I play there on Sundays, and so have regular access to the space. In addition, the premiere performance of *Spatia* was performed at Emmaus.

presents the specification of the instrument, along with the notation for the stops that is used in the score.

Pedal		**Great**		**Swell**	
Name in score	**description**	**Name in score**	**description**	**Name in score**	**description**
1	Full Organ	1	Full Organ	1	Full Organ
2	Full Organ with resonant frequencies	2	Full Organ with resonant frequencies	2	Full Organ with resonant frequencies
3	Resonant Frequencies	3	Resonant Frequencies	3	Resonant Frequencies
4	Location1Time1	4	Location1Time1	4	Location1Time1
5	Location2Time1	5	Location2Time1	5	Location2Time1
6	Location3Time1	6	Location3Time1	6	Location3Time1
7	Location1Time2	7	Location1Time2	7	Location1Time2
8	Location2Time2	8	Location2Time2	8	Location2Time2
9	Location3Time2	9	Location3Time2	9	Location3Time2

Table 6: Stop-list of the digital organ for this thesis.

Further editing was required in order to make these stops usable. I recorded the entire compass of the organ plenum sound in a single audio file, wherein each pitch sounded for approximately eight seconds, followed by approximately four seconds of silence. Because every pitch on the organ was contained in the audio, it was easier to perform the Lucier process, since I only needed to play and record a single recording rather than 61 separate recordings. However, I eventually needed to separate the recording into its constituent individual pitches so that each key on the organ could be linked to an individual pitched sample. In addition, the six stops using recorded noise from the environment had to be filtered into frequency bands (as described above). I performed both of these operations in the open-source digital audio editor Audacity. The frequency bands (with the associated keys on the keyboard) were assigned as follows:

Start frequency (in Hz)	end frequency (in Hz)	Key ranges
0 (low pass filter)	65.18518519	C2-G2
65.18518519	123.75	G#2-D#3
123.75	234.9316406	E3-B3
234.9316406	446.0030365	C4-G4
446.0030365	846.7088896	G#4-D#5
846.7088896	1607.423908	E5-B5
1607.423908	None (high pass filter)	C6-C7

Table 7: Frequency bands of the recording and their associated keys.

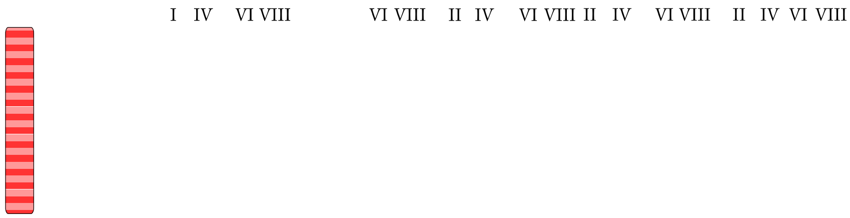


Figure 1: Full range of the organ keyboard, divided into groups of keys that play the same sample.

Each group of eight identically-patterned keys will play the same sample, but will produce the sound from a different speaker. The Roman numerals indicate which speaker will sound when a key is depressed.

The graphic above depicts the division of the organ keyboard into the frequency ranges described above. Each identically patterned key produces the same frequency-slice of a sample. The Roman numerals represent the speaker from which the sample will be played. Note that this arrangement is not octave equivalent, but instead repeats every two octaves. For example, if C2 is played, the lowest frequency-slice will sound from speaker I. However, if C3 is played, the second lowest frequency-slice will sound from speaker V instead of from speaker I. It is also important to note that the C-whole-tone scale includes all of the odd-numbered speakers, while the C#-whole tone scale includes all of the even-numbered speakers (the significance of which is discussed below).

In addition to the choice of sounds designed for an organ, one must also consider the location of the sound producers within a room. On an acoustic organ, this principle simply refers to the location of pipes within a room. Needless to say, this is something controlled by the organ builder, and is not a design element that can be specified by either the performer or the composer. However, in the case of a digital organ, one can place the sound producers (namely the loudspeakers) anywhere in the performance space. Thus, the position of sound within a room can be used as a compositional element. I have included a rough schematic of the sanctuary of Emmaus Lutheran Church on the following page, with speaker positions marked at each number. While there are no strict rules for this setup, there are general principles that must be observed to produce certain tonal qualities in a given space, which are as follows:

1. Speakers must be distributed at roughly even intervals around the room, so as to surround the audience with sound producers. If one has four speakers, it would be inappropriate to place all four speakers along one wall, as this arrangement concentrates sound in one portion of the room, rather than surrounding the audience with it.

2. The speakers should be arranged in a manner that is site-specific. The typical 5.1 or 7.1 surround-sound layout of most movie theaters is an example of a layout that must not be used. While 7.1 surrounds the audience with speakers (thus satisfying principle as stated above), it fails to utilize the particular characteristics of a performance space. Instead, one must make the speaker arrangement as site-specific as possible. For example, if this piece were performed in a church, one could place a speaker on the altar or in the place of a statute, as both the altar and statue are objects specific to the architecture of that particular church. If this were not acceptable to the members of the church, it would be acceptable to place a speaker immediately in front of the altar or in front of the statue.

3. At least two speakers must be placed immediately outside the room, in order to produce the effect of distant or muffled sound. If there are rooms attached to the performance venue (e.g. the sacristy, storage rooms), one should consider placing some speakers there. Ideally, these speakers should be located on opposite sides of the room, so that sound can be passed from one speaker to another.

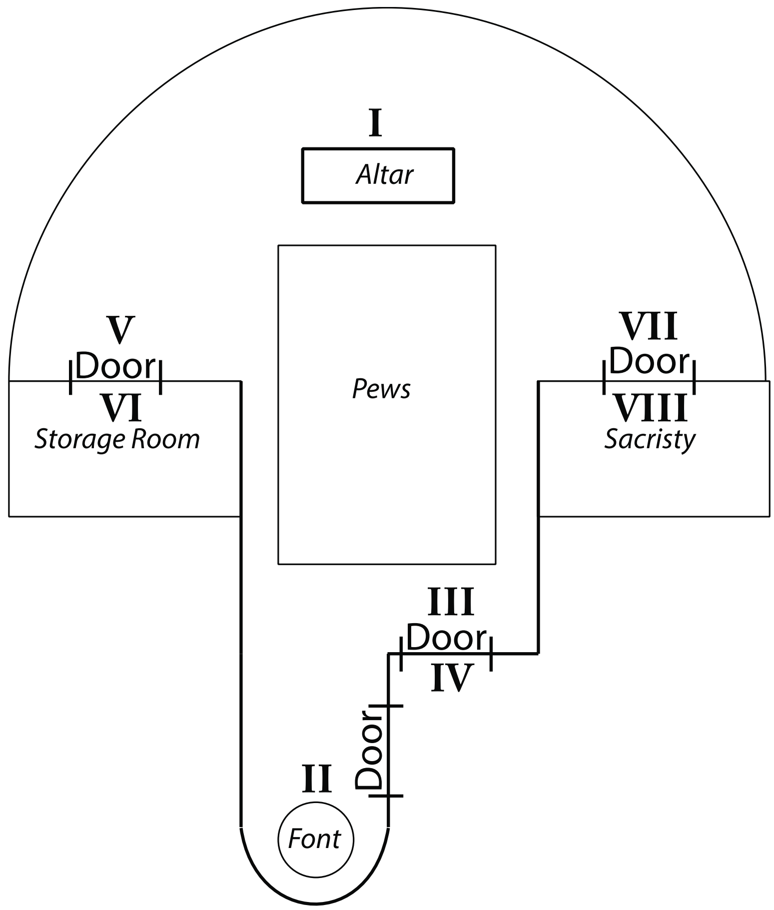


Figure 2: The location of the speakers within the sanctuary of Emmaus Lutheran Church.

The Roman numerals correspond to the keys in fig. 1.

In addition, while the arrangement of the speakers may vary from performance venue to performance, the relationship of the speakers to the keyboard must be constant. The rules for this arrangement are as follows:

1. The notes of the ascending chromatic scale should correspond to the numerical sequence of the speakers. Thus, the set (beginning on C2) of C, C#, D, Eb, E, F, F#, G will correspond to speakers I, II, III, IV, V, VI, VII, and VIII, respectively. As depicted on the keyboard graphic above, this sequence repeats across the compass of the instrument, such that the keyboard is divided into eight-note groups.

2. All odd numbered speakers shall be located inside the performance; all even-numbered speakers shall be located outside of the performance space.

3. Speaker I shall be at the front of the performance space; speaker III shall be at the rear; speakers V and VII shall be at stage right and stage left, respectively.

4. The speakers shall be grouped into the following pairs: I and II, III and IV, V and VI, VII and VIII. Each even-numbered speaker shall be as close as possible its odd-numbered counterpart, while still being located outside the performance space.

Of all the rules listed above, number 4 is the most flexible. In the diagram above, speaker II is nearer to speaker III than to speaker I. This because there are no doors near speaker I behind which speaker II can be placed. However, if one places speaker II in the location marked in the diagram above and turns the speaker so that the it projects sound towards the wall, it is possible to achieve an effect similar to the sound of the speakers actually outside of the performance space. Therefore, it is preferable to modify rule 4 (proximity) rather than to discard rule 2 (even-numbered speakers shall be outside of the performance space).

Audio files cannot be used in the Hauptwerk digital organ simulator unless they are in WAV format and are marked with loop points. This marking allows Hauptwerk to produce a continuous, unbroken sound from a sample as long as a key is depressed. In order to make loops from the base recordings, I used the LoopAuditioneer program to add loop points to the WAV files produced in Audacity. In order to run LoopAuditioneer, which exists only as a Linux and Windows application, I used the Wine program, which allows one to run Windows applications on Macintosh computers.

Instrument, Software, and Hardware Specifications

When I first began my thesis, I contacted various digital organ manufacturers to determine if there were any digital organs that could be loaded with original sound samples. As expected, no such instruments are readily available. Thus, it was necessary to explore alternatives. All major digital organs are equipped with three five-pin MIDI connectors (namely input, output, and throughput), which allow one to use the organ as a MIDI controller in order to play samples from another device. While there are several sampler programs that can receive MIDI input, there are very few that will easily integrate with the controls of an organ console. In other words, almost all MIDI sampler programs require extensive configuration in order to function like an organ. The most difficult feature to reproduce in a MIDI sampler is the stop controls, which are an essential part of a digital organ but which are not found on most MIDI samplers.

Fortunately, the Hauptwerk program can interface directly with the hardware of the digital organ. Thus, the organist can change controls on the organ console and cause changes to occur within the program. These controls include, but are not limited to, the keyboards, the pedalboard, the expression pedals, and the stop controls. When using Hauptwerk, it is still necessary to interact with the program to design and configure the virtual organ. However, once this task is complete, it is possible to manipulate the program using only the controls on the digital organ console.

The organ I used for this project is an Allen MDS-25 owned by Emmaus Lutheran Church. This organ has two manuals, a 32-note pedal, a crescendo pedal, and two swell pedals (one controlling the Swell division and a second controlling both the Great and Pedal divisions), and, most importantly, is MIDI capable. Because the MIDI signals from the organ can be assigned to any control in the Hauptwerk program, I configured the crescendo pedal (which normally adds stops in a set order) to function as a third expression pedal. Thus, I was able to independently control the volume of the Pedal, Great, and Swell divisions through three separate expression pedals. Similarly, the assignment of stops tabs on the organ console to the stops controls in Hauptwerk is entirely arbitrary and unimportant. However, it is worth repeating that the organ does have MIDI input and output capability, and that without this capacity, I would not be able to use this instrument for my project.

The MIDI signal from the organ was routed into my computer through a five-foot iConnectivity mio MIDI to USB cable. This MIDI signal controlled the production of sound and the operation of the expression pedals within the Hauptwerk program. The program then outputted a digital audio signal that was routed into an Allen and Heath QU-16 digital mixing board. The digital signal was converted to an analog audio signal, mixed, and then sent to the eight speakers in the various locations around the room.

Chapter 4: Compositional Techniques and Form

There exists a unique problem with an analysis of *Spatia* that does not exist with other musical works. Unlike the score of a Beethoven string quartet, the score of *Spatia* represents only a very small part of the actual music, namely the physical actions performed by the organist during a performance. In other words, the score to my piece is more like guitar tablature than like the score to a symphony. However, even this comparison is not quite accurate. While tablature does not directly represent pitch information, definite pitches can always be inferred from the physical action represented in the notation. For example, if the tuning of the strings of a guitar is specified in a tablature score, one can determine the pitches that will sound when a player fingers a string at a particular fret, even if that pitch is not directly notated. In contrast, the notation used in *Spatia* generally does not represent definite or discrete pitch information, even in the indirect manner of guitar tablature. As illustrated above, six of the nine stops on the organ use samples taken from the performance space. These samples have no definite pitch or timbre, and, in fact, vary according to the time and location wherein the recordings were made. In addition, the stop composed of the resonant frequencies of the performance varies in timbre and pitch content from location to location. Similarly, the stop composed of the full organ sound distorted by the resonant frequencies varies in timbre depending on the performance location. In fact, the only stop with a definite pitch content and timbre is the full organ stop, while the pitch and timbre of every other stop are variable.

Because so little pitch information is encoded in the score itself, different analytical tools must be used to interpret this music. Rather than analyzing patterns of harmonies and melodies, I will instead interpret this piece as an elaboration of a background structure using two sonic transformations, a simple registral pattern, and a minimally altered contrapuntal theme.[60] The two transformations are as follows. If a sample is being played on one speaker either inside or outside of the performance space, it may subsequently be played on a different speaker in the same acoustical environment as the first speaker. This sequence changes the location of the sound production, though only between speakers inside or outside the room. In other words, this transformation can move the source of sound within the performance space or between the speakers outside of the performance space, but it may not move sound from inside to outside of the performance space (or vice-versa). The transformation is represented by a sequence of notes drawn exclusively from either the C whole-tone scale (i.e. the set C-D-E-F#-G#/Ab-Bb), as represented in the example below, or the C# whole-tone scale (the set C#-D#/Eb, F, G, A, B).

Figure 3: An example of transformation 1.

In contrast, the second transformation shifts the source of sound production from inside the performance space to outside the performance (or vice-versa). This is represented in the score as a shift from the C whole-tone scale (C-D-E-F#-G#/Ab-Bb) to the Db whole-tone scale (C#/Db-Eb-F-G-A-B), if moving from inside to outside, or

[60] Music theorists will note the emphasis on background structure is similar to Schenkerian analysis, and the emphasis on surface level transformations bares some similarity to neo-Riemannian theory. However, as *Spatia* is not a work of tonal music with a clear harmonic language (functional or not), and as considerations of pitch were secondary to the compositional process, it is not fruitful to discuss the similarities to Schenker or Riemann here.

the reverse, if moving from outside to inside. This transformation is represented in the figure below:

Figure 4: An example of transformation 2.

Combinations and elaborations of these two transformations form the largest portion of the piece. However, one should note that these transformations can only be applied to the six stops composed of recorded samples, as these are the only stops that sound from an individual speaker (as opposed to the resonant frequency and full organ stops which sound simultaneously from every speaker whenever they are played).

The registral motive was created to solve a technical problem that resulted from the particular choice of stops on the digital organ. As described above, the six sample-stops do not produce discrete pitches or clear rhythms. This presents a problem when composing a theme and motives, which are traditionally defined as melodic, harmonic, and/or rhythmic patterns. It would sound incongruous to use any of these types of motives on the full organ stop, because nothing melodic, harmonic, or rhythmic can be produced by the six sample stops. When played on any of the full organ or resonant-frequency stops, cluster chords effectively imitate the noisy sound of the six sample-stops. If these cluster chords are presented in an ascending or descending sequence, a semblance of a melody is created. The motive I composed is a very simple progression of a high cluster-chord followed by a low-cluster chord. This progression creates the perception of a melody that begins high and ends low. This version of the motive is presented below. The motive can also be inverted and presented as a melody that begins low and ends high. The two forms of the motive can be distinguished by the affective character: the prime form of the motive (high to low) suggests the conclusion of a phrase, while the inverted form suggests that a phrase is waiting to be completed.

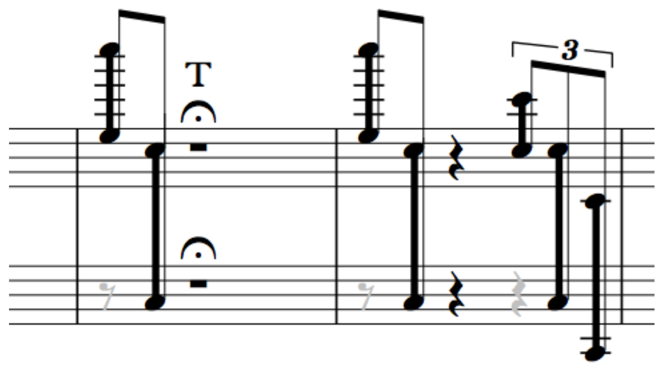


Figure 5: An example of the registral motive.

Finally, the minimally altered theme consists of a counterpoint of alternating octaves and fifths[61] played on either or both of the resonant frequency stops. This theme is unique in one significant aspect. Unlike the transformations that are applied to the sampled stops, or the treble-to-bass gesture that appears with the full organ stop, the counterpoint theme most closely approximates the harmonic, textural, and melodic language of a previous era (namely, the Middle Ages). However, it would be a mistake to consider this theme to be merely an imitation of medieval polyphony. The counterpoint is simply too chromatic. Instead, the contrapuntal theme represents a deliberate attempt on my part to compose music that will be effective in a variety of performance spaces. It is a near impossibility that two performance spaces will have the same (or even similar) resonant frequencies. As such, a melody line played on the resonant frequency stops will have two totally different characters in two different

[61] This counterpoint also includes the compound intervals of the 12th (i.e. an octave and a fifth) and the 15th (i.e. the double octave), which I treat as roughly equivalent to the fifth and octave, respectively.

performance spaces. A melody played in a particular key (D major, for example) could be unbearably loud in one space (if the tones of the key happen to be resonant frequencies) or could be virtually inaudible in another space (if the tones of the key are not resonant frequencies). It follows that a melody in any particular key will not sound reliably across the entire range of spaces in which *Spatia* might be performed. My solution was to compose a highly chromatic counterpoint which uses all of the notes of the pedalboard over the course of the piece, and which uses most of the notes of the chromatic scale within any particular passage. Because the counterpoint includes so many pitches in quick succession, a variety of tone colors are produced as the music cycles through frequencies that do resonate in the performance space and frequencies that do not. The overall effect sounds more like the spectral music of Tristan Murail and Gérard Grisey than medieval polyphony. When this polyphonic theme occurs, it acts to thicken the texture and not to provide concrete harmonic support.

Figure 6: An excerpt from the contrapuntal theme.

These four compositional devices form the basis for the entire work. *Spatia* begins with a cacophonous cluster-chord that consists of every pitch of every stop sounding at once. It is as if the entire organ is speaking with a single tremendous voice in this single massive sonority. Yet this cluster is incredibly brief, and acts as an impulse of noise that causes the entire room to ring with noise. From measures 1 to 34, this cluster is elaborated, first by changing the size of the cluster, and then by changing the rhythm in which it is played. In the next section, the registral motive is presented. Initially, the motive is only implied: the reduction in size of the initial cluster from five octaves to the bottom two octaves suggests a downward motion from treble to bass. In measure 12, this figure is presented explicitly in the descent from the C5-C7 cluster to the C2-B2 cluster. However, while the apparent motion in measure 12 is descending, measure 12 is merely an elaborated copy of measure 7, but sounded three octaves higher. Thus, while the surface level motive is descending from the highest treble notes to the lowest bass pitches, the deeper structural gesture is the inverse, ascending from lowest pitches to the highest. At the same time, the deepest structural level of measures 1 through 34 is fundamentally static. The cluster chord that begins the piece in measure 1 concludes the section in measure 34. All of the cluster-chords in between measures 1 and 34 are simply elaborating the chords at the beginning and end of the section. Yet, while the section begins with a brief sonic impulse, it concludes with true chaos as the cluster-chord that began the piece now sounds for 15 seconds.

The next section, which begins at measure 36, presents a variation on the material in the previous section, but does not initially present any fundamentally new themes or motives. The bass to treble motion in measure 36 is simply an inversion of the treble to bass motion described above. And while this passage is played on a new registration (which lacks the full organ sound of the first 34 bars), the passage seems to be little more than an elaboration of what has already been presented. Yet, in measure 39, a C whole-tone cluster appears, while previously the only clusters were chromatic. At first, it appears this cluster is unimportant, or perhaps even a mistake, as the music quickly returns to the elaboration of chromatic cluster-chords. However, in measure 56, the whole-tone cluster becomes a generative element in the form of the outside-to-inside sonic transformation described above. The section concludes with another 15 second chromatic cluster-chord, analogous to the cluster in measure 34, which gradually fades into silence.

Measure 65 introduces a radically new texture. Hitherto, the primary sound has been composed of chromatic clusters interspersed with abrupt silences. Suddenly, actual consonances (i.e. fifths and octaves) appear, although they form the contrapuntal theme and, as described above, appear more for timbre than for harmony or melody. While this theme is presented in the pedal, the manuals accompany it with the six sample stops. This accompanimental figure is the first instance of the speaker-to-speaker transformation described above. In measure 66, two frequency-slices are played on speakers I and III, followed by the next higher pair of frequency slices played on speakers V and VII. In measure 68, the roles are reversed, with the lower pair of frequency-slices played on speakers V and VII and the upper pair played on speakers I and III. This demonstrates the use of a pair of linked transformations, wherein the sound produced on one pair of speakers is switched with the sound produced on another pair of speakers.

The accompaniment drops out in measure 71, while the contrapuntal theme continues into measure 80. In measure 75, a new accompanimental figure is introduced. The third and fourth lowest frequency-slices are played on speakers II and IV in long tones while the next highest frequency-slice is passed between speakers II, IV, VI, and VIII, and sounding in a different speaker every beat. This texture creates an opposition between the lower frequency-slices, which sound continuously for ten seconds, and the higher frequency-slice, which sounds for only two seconds on any given speaker at a time. In addition, there is an opposition between the spatial stasis of the lower frequency-slices, which sound from only two speakers for an extended length of time, and the higher frequency-slice, which sounds from a new speaker every second. In measure 76, the passage is altered through the interior-exterior transformation. The entire passage is repeated down one half-step such that the long samples that sounded on speakers II and IV now sound on speakers I and III (their companion interior speakers). Similarly, the spatially mobile pattern that passed sound between speakers II, IV, VI, and VIII now passes sound between speakers I, III, V, and VII.

This texture continues until measure 82, where it is interrupted by a six-second long C whole tone cluster. The accompanimental figure resumes again in measure 83, but with two significant changes. First, the accompaniment in measures 66 through 81 uses all of the six sample stops. In contrast, the accompaniment beginning in measure 83 uses the six sample stops in two groups of three. Stops 4, 5, and 6 (the three stops featuring recordings taken at time 1) are played on the Swell, while stops 7, 8, and 9 (the three stops featuring recordings taken at time 2) are played on the Great. With this arrangement of the stops, a dialogue can be composed between the sounds of the space recorded at two different moments in time. The second difference between the accompaniments in measures 75 and 84 is that the latter is an augmentation of the former. Whereas the accompaniment beginning in 75 is a four-second cycle, wherein each speaker sounds for two seconds, the accompaniment beginning in measure 84 is an eight-second cycle, wherein each speaker sounds for three seconds. Because each sample sounds for longer and the spatial motion of the sound occurs less rapidly, the overall character of the accompaniment (such as in measure 84) is less fragmented and chaotic. This figure is augmented again in measures 89 through 91, where it becomes a sixteen-second cycle with each speaker sounding for four seconds. In addition, the opposition between the time 1 stops and the time 2 stops is most pronounced in measures 89 through 91. In this passage, the accompanimental figure is repeated alternately on the Swell and Great, and as such, repeats the same sequence of speakers and frequency-slices on the time 1 and time 2 stops.

The music described above constitutes two distinct sections. The first section is from measures 1 to 64 and functions principally as an exposition. As described above, measures 1 through 34 elaborate on a single cluster-chord and introduce the treble-to-bass motion, while measures 36 through 63 elaborate the same cluster-chord and present the interior-exterior transformation. Therefore, at the deepest structural level, the entire first section is a single cluster-chord elaborated by the treble-to-bass motion and the interior-exterior transformation in the middleground, and decorated with additional surface-level elaborations. The next section (65-92) both develops the interior-exterior transformation and introduces the speaker-to-speaker transformation and the contrapuntal theme. Over the course of these two passages (measures 1-64 and 65-92), the entire motivic basis of the piece is introduced and slightly developed.

It is in measure 93 that the true development begins. A series of cluster-chords is in the Great, which now plays the full organ stop in addition to stops 7, 8, and 9. This texture suggests a return to the music of measures 1 through 34. However, unlike the cluster-chords used in measures 1-34, which are generally larger than an octave, the clusters that appear beginning in 93 are mostly the size of fifths or sixths (and so are more like the clusters in 36-63). Moreover, the predominant motion of these clusters is from bass to treble, rather than from treble to bass. Thus, this passage is a combination of the timbre of 1-34 (primarily full organ), the surface level motives of 36-63, and the inverse of the treble-bass registral gesture.

The clusters of this passage are interspersed with passages played on stops 4, 5, and 6 on the Swell, which incorporate and develop the two sonic transformations described above. In measures 96, two frequency-slices begin sounding simultaneously from speaker VI and two more frequency slices begin sounding from speaker VIII two seconds later. In measure 97, this passage is repeated, but with a twist. One might expect measure 97 to begin with speaker VIII and continue with speaker VI (in other words, a speaker-to-speaker transformation of measure 96) or to begin with speaker V and continue with speaker VII (thereby swapping VI and VIII for their interior counterparts in an interior-exterior transformation). Instead, the passage begins with two frequency-slices sounding from speaker VII and then sounding from speaker V two seconds later. Thus, the transformation of measure 96 into measure 97 is combination of both the speaker-to-speaker transformation and the interior-exterior transformation. This is the first simultaneous combination of both of these transformations, and is highly significant in the course of the development of the piece.

In measures 102 through 106, the opposition between the full organ timbre and the sample stops disappears. In this passage, the long notes of the Swell (which plays the sample stops) accompany the cluster-chords played on the Great (which plays the full organ timbre). The cluster-chord gesture combines the inverted bass-to-treble motion of the previous passage with the original treble-to-bass gesture, such that an arching gesture (of the form bass-treble-bass) is produced. A speaker-speaker transformation in the Swell moves the sound from speakers V and VII to speakers I and III, which thereby anticipates the next section.

Two significant developments occur in measures 107 through 136. The first (and simplest) development is the presentation of yet another configuration of the speaker-speaker and interior-exterior transformations. Whereas in measure 96-97, the two transformations occurred simultaneously, in measure 107, the transformations occur sequentially and at different structural levels. In measure 107, two frequency-slices sound for two seconds from speaker V, two seconds from speaker VII, two seconds from speaker VI, and two seconds from VIII. This amounts to a speaker-speaker transformation from speaker V to VII, and an interior-exterior transformation from the pair of speakers V and VII to speakers VI and VIII. The combined transformation is first repeated under diminution (where each speaker sounds for only one second) in measures 108 and 110, and the again under augmentation (where each speaker sounds for three seconds) in measures 111 and 112. The latter iteration is almost identical to the augmented accompanimental figure in measure 84.

The second major development in this section is the change in registration. Previously in the piece, stops had been chosen to create particular oppositions, which appeared in the piece in the following order: (1) full organ vs. everything else; (2) samples vs. resonant frequencies; (3) samples taken at time 1 vs. samples taken at time 2; and (4) full organ vs. time 1 samples. In measures 107 through 136, the primary opposition is between samples recorded at different locations and not between samples recorded at different times. Thus, in measure 107 the Great is set to stops 4 and 7 (the stops that feature recordings taken inside the performance space at time 1 and 2, respectively), while in measure 115, the Swell is set to stops 6 and 9 (the stops that feature recordings taken outside of the performance building at time 1 and 2, respectively). Because the stops on the Great are changed before those on the Swell, there is thematic confusion from 107 to 114 until the opposition between locations is established by the change of the Swell stops in measure 115.

This opposition between locations is further complicated in measure 125. In measures 115 through 120, the Swell plays patterns formed from the speaker-speaker transformation while the Great plays a C# whole-tone cluster as accompaniment. In measures 121, the Swell plays a pattern formed through a sequence of speaker-speaker transformations, followed a pair of interior-exterior transformations in measure 122. The Great repeats these figures in measures 123 and 124. This repetition asserts the clear opposition between the location 1 recordings (taken inside the performance space) and the location 2 recordings (taken outside the performance building). Suddenly, in measure 125, the manuals drop out, and, instead, the pedal plays a brief portion of the contrapuntal theme using the resonant frequency stop. This theme is followed by a sequence of speaker-speaker transformations of the Swell in measure 126, followed by similar sequence of speaker-speaker transformations and a statement of the Great in measure 127. This trialogue presents a new opposition. Whereas previously, the sounds of different locations were fighting for musical primacy, now the sounds of the different locations are also struggling with the natural acoustical resonances of the space itself. It is as if the sounds created by humans were struggling against the sounds of the space itself. The three-way opposition continues into measure 128 to 133, although the Great changes from stops 4 and 7 to stops 5 and 8 (i.e. the stops featuring recordings made outside the performance space but within the building) in measure 131. In measure 134, the opposition ceases entirely. Instead, the pedal plays the contrapuntal theme while the Great accompanies with a chromatic cluster in the lowest octave of the keyboard. This is the first instance of a chromatic cluster being played on sample stops alone, and it seems to signal the beginning of a recapitulation.

Indeed, measures 137 through 140 seem to further suggest the beginning of a recapitulation. The Great plays all six sample stops in a large C# whole-tone cluster arpeggio leading to a C whole-tone scale arpeggio. This is a combination of an interior-exterior transformation and a bass-treble motion, which is analogous to a similar passage in measure 60-61. However, this recapitulation turns out to be spurious. The enormous chords of 137-138 give way to the most delicate music of the entire piece. The Swell, playing only a single stop (stop 4), shifts frequency-slices around the performance space through a sequence of speaker-speaker transformation. The Great, still playing all six sample stops, enters in 144, as if to force the music towards a recapitulation. Ultimately, this attempt fails, and even the Great is reduced to a single stop (stop 4). The Pedal enters in measure 153, and, for eight seconds in measure 154, all of the three divisions are playing the same stop (namely stop 4, which is the stop featuring a recording taken in the performance at time 1).

However, this sonic unity exists only for the span of measure 154. In measure 155, the Great begins to play stop 5, and in measure 158, the Great begins to play the accompanimental figure from measure 75 (which is derived from the speaker-speaker transformation). Against this accompaniment, the Swell plays a highly augmented version of the same motive on stop 8. In measure 161, the roles are reversed: the Swell now plays the accompanimental figure from measure 75 (although slightly augmented) while the Great plays the highly augmented version of the motive. The change of roles in this passage also constitutes a large scale interior-exterior transformation. Each iteration of the accompanimental figure (whether unaugmented or slightly augmented) is played on a C# whole-tone scale (and, by extension, on the exterior speakers). In contrast, each iteration of the highly augmented motive is played on a C whole-tone scale (and, by extension, on the interior speakers). When the Great and Swell change roles, the set of speakers they control also changes. As the Great and Swell each play a single stop in this section (stops 5 and 8, respectively), this change also effects the speakers from which each stop sounds. This interior-exterior transformation is more important as a structural and developmental feature than is the configuration of the various figures between the Swell and Great.

The music described above from measures 93 through 164 constitute the development. *Spatia* does not fit the standard model of the clearly delineated classical form. Nonetheless, the piece has a few clear formal divisions. As described above, measures 1 through 95 constitute a kind of exposition, while measures 93 through 164 constitute a development section. Naturally, measures 165 through 208 act as a conclusion or recapitulation, and measures 209 through 216 form an epilogue or coda. The exposition presents a tone cluster and two compositional devices, and then proceeds to deconstruct the tone cluster and slightly develop the compositional devices. The development continues to deconstruct the tone cluster, presents two more compositional devices, and explores some of the possible combinations of the material.

It follows that the conclusion undoes the work of the development by simplifying the music and reconstructing the tone cluster.

The first stage of this reconstruction is measures 165 through 169. In this passage, the Swell plays material from measures 36 through 63 on the full organ stop. This figure is joined in measure 169 by the Great, which plays the resonant frequency stop (i.e. stop 3) in the highest register of the keyboard. This initially appears to be an entirely new development in the piece, as thus far stop 3 has only appeared independently when it is used to play the contrapuntal theme. Yet while this use of stop 3 is new, the material it plays is not. The figure in measures 169 through 170 is derived from similar material in measures 1 through 34, and the gesture played in the Great in measures 171 through 173 is a near identical copy of measures 56 through 58. The resonant frequency stop in the Great is joined by stop 2 (the mixed organ/resonant frequency stop) in the pedal in measure 175, which once again plays the contrapuntal theme. Initially, these two are in opposition to the full organ stop in the Swell, as exemplified by measure 179. However, this opposition quickly dissolves and in measures 183 through 186 the Swell plays in consort with the Pedal and Great. This section of the recapitulation ends with a figure on the full organ stop on the swell that combines measure 49-51 and measure 1.

Thus far, the reconstruction of the initial tone cluster has only included stops 1, 2, 3, (i.e. the full organ stop and the two resonant frequency stops). To return to the initial tone cluster (which included every pitch and every stop on the organ), the six sample stops must be added. In measures 189-190, the Great plays an augmented version of the accompaniment from measure 75 with stops 7, 8, and 9 (the three stops recorded at time 2). This is immediately followed by the same figure plated on the Swell with stops 4, 5, and 6 (the three stops recorded at time 1). In measures 192 through 195, the Great and Swell alternate playing the 16 second version of the accompaniment from measure 75 on stops 7, 8, and 9 and 4, 5, and 6, respectively. In measures 196 through 199, the previous passage is altered by an interior-exterior transformation, which increases the volume of the passage and leads into the final gargantuan cluster-chord. The initial cluster is almost rebuilt in measures 200 through 202, where the Great plays the five highest frequency-slices of the six sample stops in a sequence that passes the sound through each of the four interior speakers. Finally, the initial cluster chord arrives in measure 203, where the Great plays every note of every stop on the organ. A highly condensed form of measures 1 through 33 is presented in measures 204 through 207, followed by a final thunderous six-second statement of the initial cluster chord in measure 208.

The piece is structurally complete at this point. The initial chord has been deconstructed and reconstructed. The piece has completed the necessary cycle of transformations and returned to its beginning. Yet this finale feels incomplete and unsatisfying. Thus, measures 209 through 216 form a coda, in order to create a sense of closure. If the chord was simply released, then there would be an echo as the various partials of the sound decayed at different rates. In the coda, the large cluster-chord is held while the stops are taken off, one or two at a time. This process produces the effect of a prolonged echo decay, even while the chord is still being held. By measure 215, only stops 6 and 9 (namely, the two stops featuring recordings taken outside the performance building) remain in the chord. The audience is presented with noise of the world outside the building as a dismissal, which sends them out from the performance into the acoustical world at large.

The organ is a fascinating instrument with a lengthy 2000-year history. The instrument has changed significantly from the simple medieval instrument that could produce only a single tone-color. The digital organ is the modern form of the organ that can best capture the possibilities of electronic music. Yet, builders of digital organs have thus far only attempted to recreate features of acoustic instruments. This has left the digital organ in limbo without the possibility of fully incorporating digital sampling and sound synthesis, and thus, it has not evolved into an instrument that is musically distinct from the acoustic pipe organ. Consequently, composers have ignored the digital organ, electing to create works for site-specific pipe organs, or for synthesizers.

This thesis project demonstrates the new opportunities for creativity that are available with the digital organ. Whereas the pipe organ can only those produce sounds that can be created by physical pipes, computers can create a large number of sounds that can not be found in nature. This project used only very basic manipulation of recordings to produce the sample set. But the digital organ, with its capacity to interface with computers, can produce far more than what is presented in this thesis. In particular, the digital organ could be combined with MaxMSP or Kyma (two powerful audio synthesis programs) to create stops that change in pitch and timbre over the course of a performance. While it is impossible to know if this thesis will stimulate further composition in this vein, at the very least, it will provide an example of new ways to compose for digital organ.

Appendix: Score of *Spatia*

Spatia

[place; date]

for solo digital organ

Alexander Bean

Performance Instructions

Spatia is a work that specifically utilizes the unique capacities of the digital organ. As such, this work cannot be performed on an acoustic pipe organ, and such a travesty should not be attempted. In order to prepare and perform this work, the organist must have access to the following: eight speakers of suffient volume and quality to fill the performance space without distortion; (2) a digital organ with MIDI capability, two manuals, a full pedal board, and three expression pedals; and (3) a computer with either of the Hauptwerk or Grand Orgue programs. It is also helpful (though not essential) to have a soundboard to mix the audio output from the computer and send it to the speakers. If the available organ does not have three expression pedals, one pedal may be configured to control the volume on both the pedal and the great, but this is not desirable.

Unlike all works for pipe organ, every new performance of *Spatia* must use a new sample set. This is reflected in the title of the composition. The general title *Spatia: [place, date]* appears in the score, but the title printed in a program must state the place and dates when the recordings for the digital organ were made. Thus, the premiere of this work was entitled *Spatia: Emmaus Lutheran Church; May 4th and 8th, 2016*. Moreover, every new performance of this work must use new samples, which are to be recorded as near to the performance date as possible.

There are nine stops, which each appear on the great, swell, and pedal divisions. When designing the organ in Hauptwerk or Grand Orgue, the organists keep the three copies of the nine stops separate so that the equivalent sounds on each division may be manipulated independently by their respective expression pedals. Six of these nine stops feature recordings taken from the performance space. Three of these recording must be made at one particular time, and three must be made at another time. For example, three recording might be made in the morning and three might be made in the evening of the same day. However, these recordings could be made on different days, provided they are all made near the performance date. In addition, two recordings must be made in the performance space, two must be made within the same building as the performance space, and two must be made outside of the performance building.

There is also one stop that features the sound of the full organ, and two stops which feature the sound of the resonant frequencies of the performance space. The first can be made by simply recording the entire compass of the organ, played one note at a time, with all of the stops pulled. To produce the two stops featuring the resonant frequencies of the performance space, one must do the following process: Take the initial recording of the full organ sound. Play this sound into the performance space and record the result. This will produce a recording of the full organ sound slightly distorted by the resonant frequencies of the performance space. One can play this new recording into the space, record the result, and obtain a recording with yet more distortion. After several iterations (about nine or ten in my experience), one will obtain a recording of only the resonant frequencies of the performance space. This will serve as one of the two stops that feature resonant frequencies. One will then choose an intermediate recording from this process (i.e. a recording of the full organ sound significantly but not entirely distorted by the resonant frequencies) to serve as the last stop. The exact specification for this instrument may be found below

Specifications

Conceptual Organization

	Time 1	Time 1	Stops Featuring organ sounds
Location 1	Location1Time1	Location1Time2	Full organ
Location 2	Location2Time1	Location2Time2	Full organ with resonant frequencies
Location 3	Location3Time1	Location2Time2	Resonant Frequencies

Digital Organ Stoplist

Pedal		Swell		Great	
Name in score	**Description**	**Name in score**	**Description**	**Name in score**	**Description**
1	Full Organ	1	Full Organ	1	Full Organ
2	Full organ with reso-nant frequencies	2	Full organ with reso-nant frequencies	2	Full organ with reso-nant frequencies
3	Resonant Frequencies	3	Resonant Frequencies	3	Resonant Frequencies
4	Location1Time1	4	Location1Time1	4	Location1Time1
5	Location2Time1	5	Location2Time1	5	Location2Time1
6	Location3Time1	6	Location3Time1	6	Location3Time1
7	Location1Time2	7	Location1Time2	7	Location1Time2
8	Location2Time2	8	Location2Time2	8	Location2Time2
9	Location2Time2	9	Location2Time2	9	Location2Time2

Division of Recordings

Before the six stops that feature records of the performance area can be used on the organ, they must first be split into bands of frequencies. This is to allow the sounds to be desconstructed and reconstructed over the course of the piece. Through trial and error, I have found that the following frequency bands work very well. The organist may elect to change the size of the frequency bands, so long as their number and relative position from high to low remains the same.

Start frequency (in Hz)	**end frequency (in Hz)**	**Ranges on the keyboard**
0 (low pass filter)	65.18518519	C2-G2
65.18518519	123.75	G#2-D#3
123.75	234.9316406	E3-B3
234.9316406	446.0030365	C4-G4
446.0030365	846.7088896	G#4-D#5
846.7088896	1607.423908	E5-B5
1607.423908	None (high pass filter)	C6-C7

Speaker placement

Unlike the pipes of an acoustic pipe organ, which are fixed in location, the speakers of a digital organ may be easily moved around the performance space. In order to most effectively use the acoustic architecture of a performance space, I have provided several principles to follow when deciding speaker placement.

1. Speakers must be distributed at roughly even intervals around the room, so as to surround the audience with sound producers. If one has four speakers, it would be inappropriate to place all four speakers along one wall, as this arrangement concentrates sound in one portion of the room, rather than surrounding the audience with it.

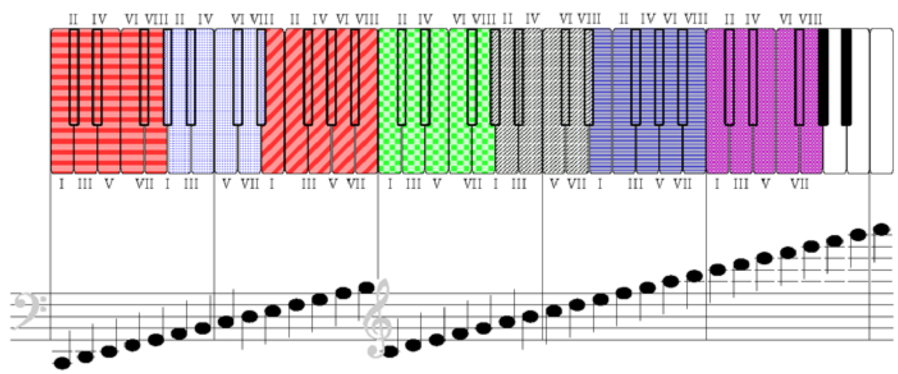
2. The speakers should be arranged in a manner that is site-specific. The typical 5.1 or 7.1 surround-sound layout of most movie theaters is an example of a layout that must not be used. While 7.1 surrounds the audience with speakers (thus satisfying principle as stated above), it fails to utilize the particular characteristics of a performance space. Instead, one must make the speaker arrangement as site-specific as possible. For example, if this piece were performed in a church, one could place a speaker on the altar or in the place of a statute, as both the altar and statue are objects specific to the architecture of that particular church. If this were not acceptable to the members of the church, it would be acceptable to place a speaker immediately in front of the altar or in front of the statue.

3. At least two speakers must be placed immediately outside the room, in order to produce the effect of distant or muffled sound. If there are rooms attached to the performance venue (e.g. the sacristy, storage rooms), one should consider placing some speakers there. Ideally, these speakers should be located on opposite sides of the room, so that sound can be passed from one speaker to another.

Stops 1, 2, and 3 (i.e. the full organ and resonant frequency stops) shall sound from all eight speakers. Stops 4, 5, 6, 7, 8, and 9 (the six stops featuring recordings taken from the performance area) will

Speaker placement cont.

Stops 1, 2, and 3 (i.e. the full organ and resonant frequency stops) shall sound from all eight speakers. Stops 4, 5, 6, 7, 8, and 9 (the six stops featuring recordings taken from the performance area) must be able to sound on each of the eight speakers. In order to be able to do this, it is best to arrange the frequency slices of each stop on the keyboard as shown on the following diagram. Everyidentically patterned key produces the same sound on the speaker indicated by the Roman numeral directly above or underneath the key in question.



There are four principles regarding the relationship of the speakers to the keyboard:

1. The notes of the ascending chromatic scale should correspond to the numerical sequence of the speakers. Thus, the set (beginning on C2) of C, C#, D, Eb, E, F, F#, G will correspond to speakers I, II, III, IV, V, VI, VII, and VIII, respectively. As depicted on the keyboard graphic above, this sequence repeats across the compass of the instrument, such that the keyboard is divided into eight-note groups.
2. All odd numbered speakers shall be located inside the performance; all even-numbered speakers shall be located outside of the performance space.
3. Speaker I shall be at the front of the performance space; speaker III shall be at the rear; speakers V and VII shall be at stage right and stage left, respectively.
4. The speakers shall be grouped into the following pairs: I and II, III and IV, V and VI, VII and VIII. Each even-numbered speaker shall be as close as possible its odd-numbered counterpart, while still being located outside the performance space.

Guide to Notation

1. A "black-note" tone cluster. Hold as many notes of the chromatic scale as possible between the two given pitches for the duration indicated by the notehead. The different notations only correspond to the graphical requirements of different noteheads and should be performed identically.

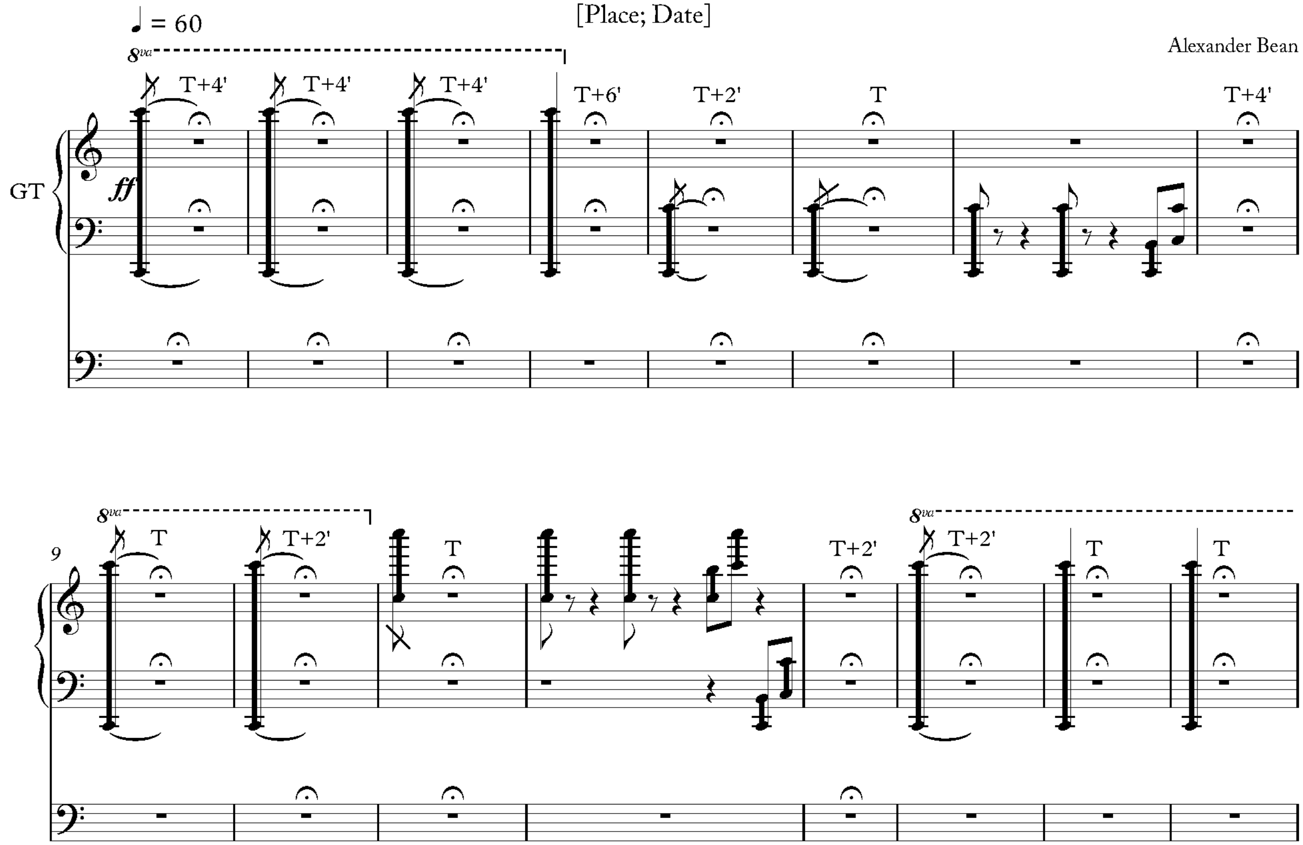
2. Do not play for the time indicated. In all cases of this notation, "T" refers the decay time of the sound immediately played. In this example, do not play until the sound of the C2-C4 cluster has completely decayed and then immediately play the next sound notated. The T marker can be extended by any number of seconds. For example, the mark (T+6") means to wait until the sound has totally decayed, and then wait for six more seconds.

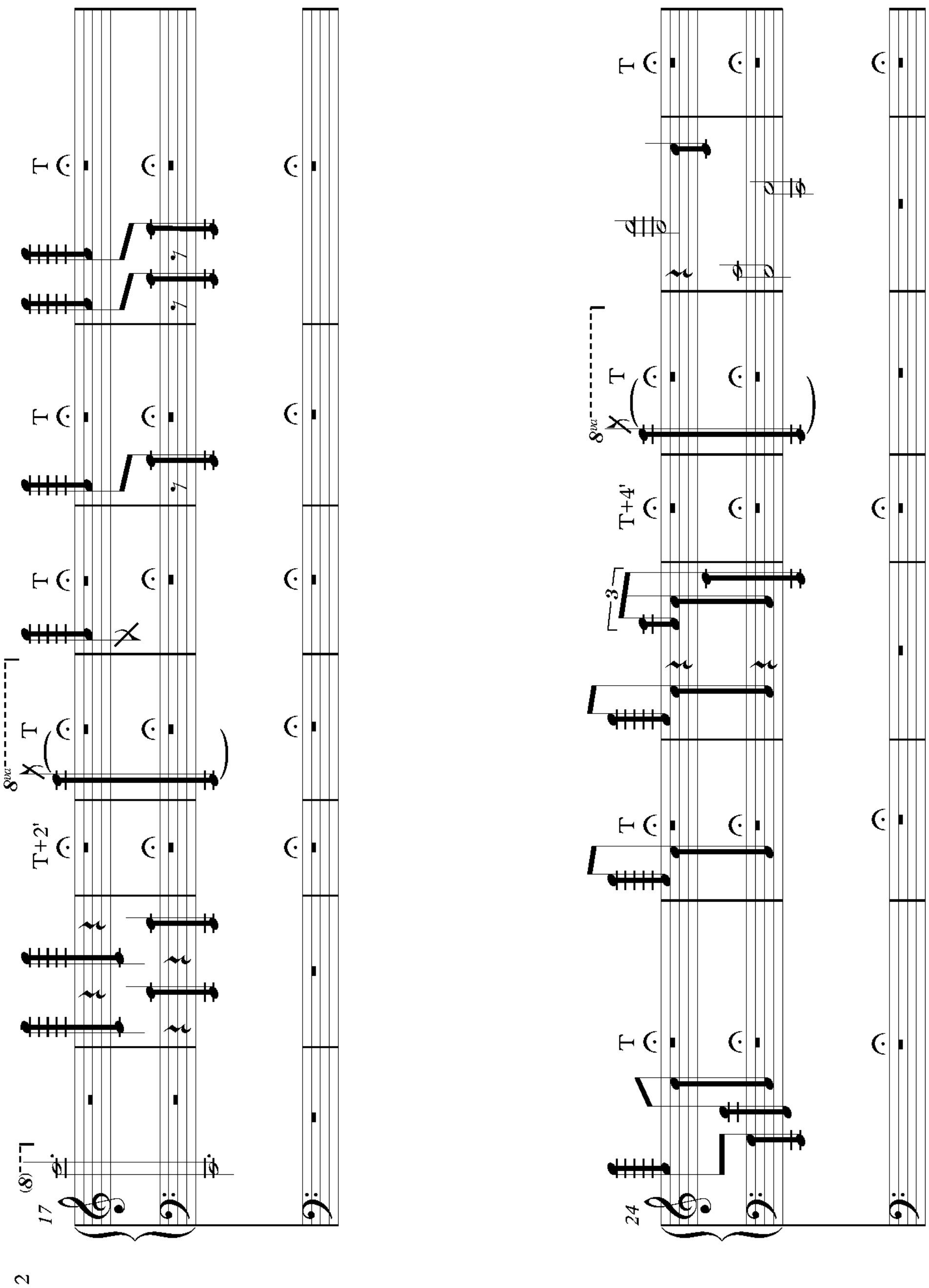
GT=1,2,3,4,5,6,7,8,9
SW=2,3,4,5,6,7,8
PED=2,3

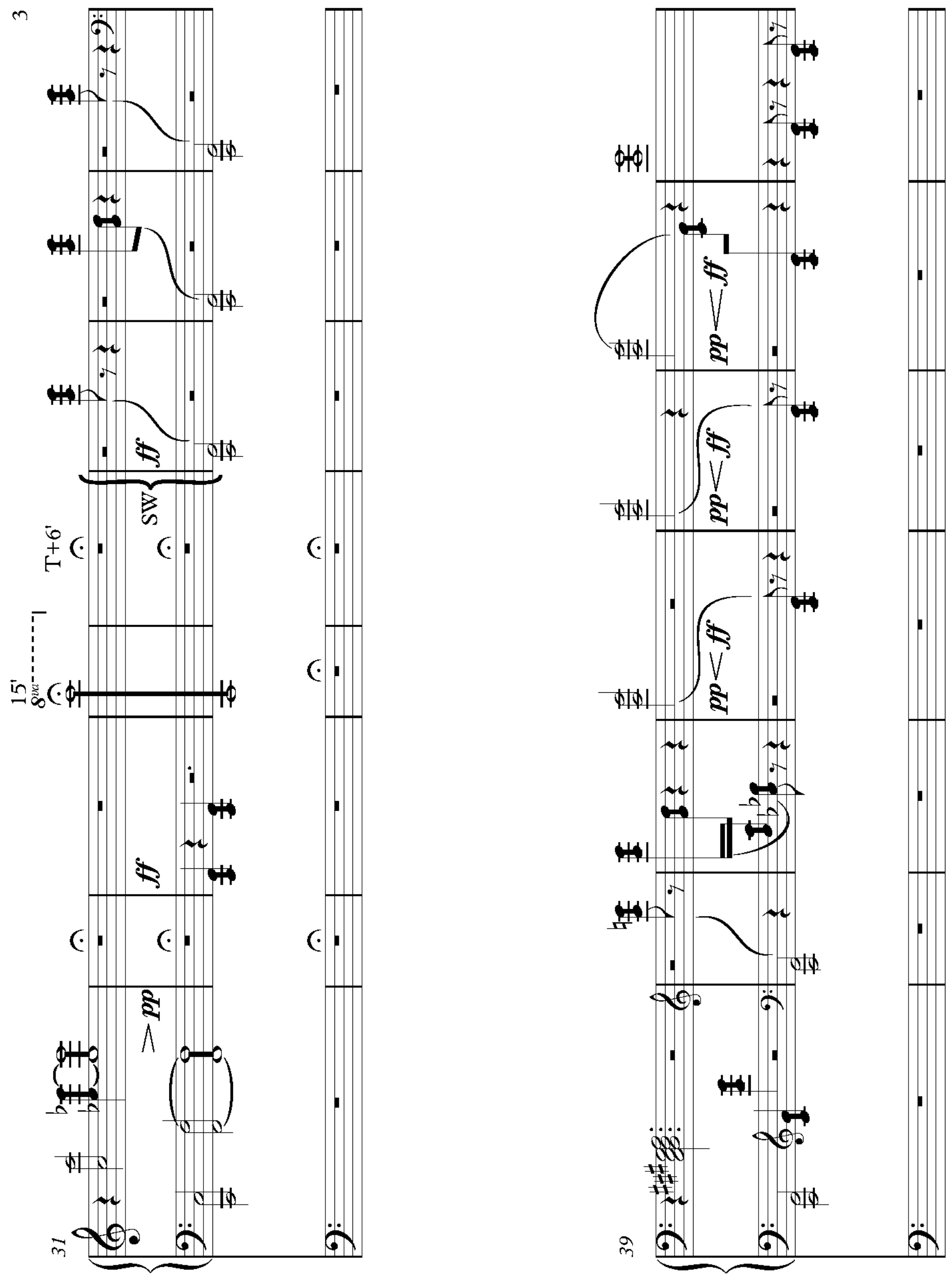
Spatia

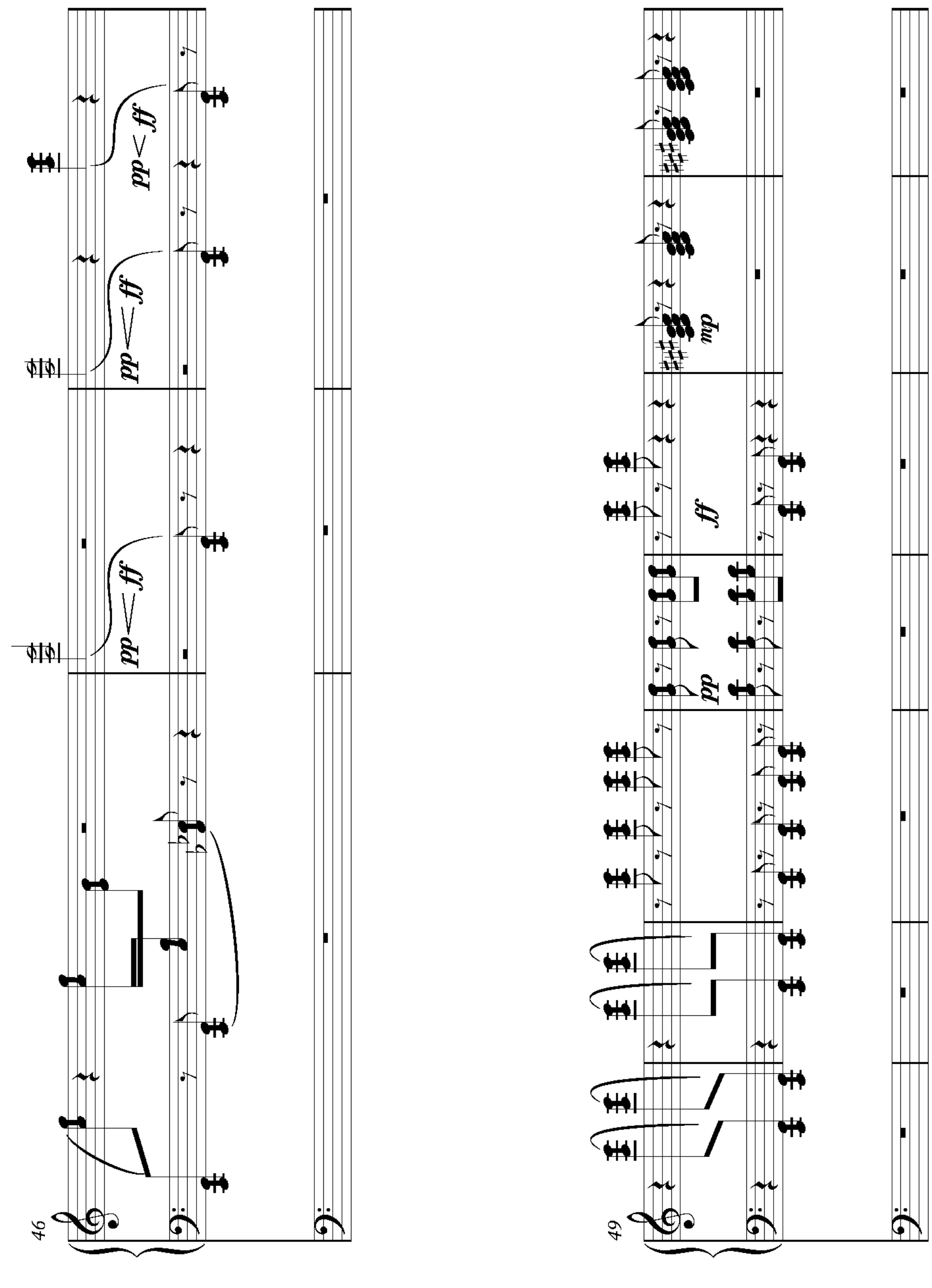
[Place; Date]

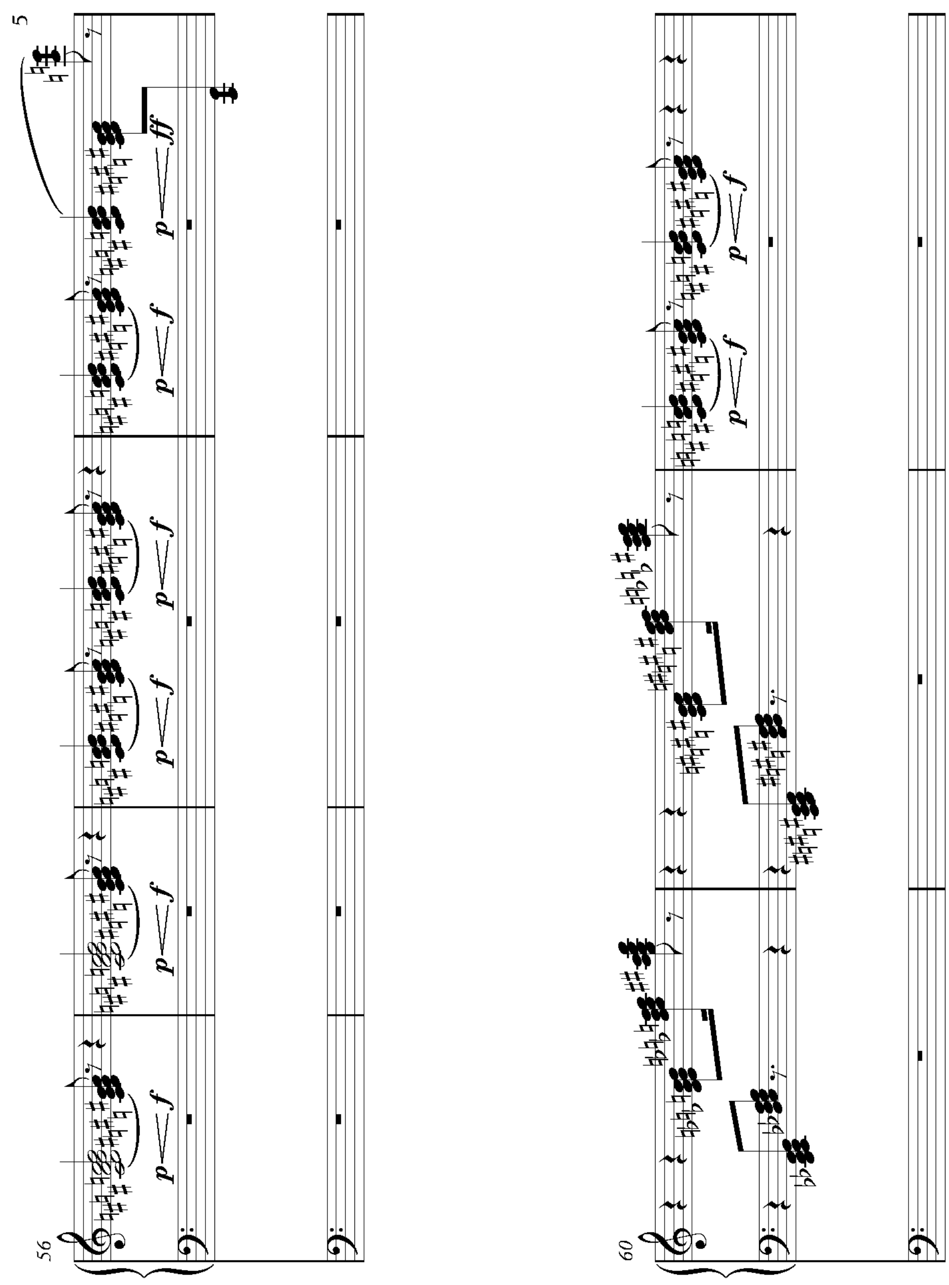
Alexander Bean

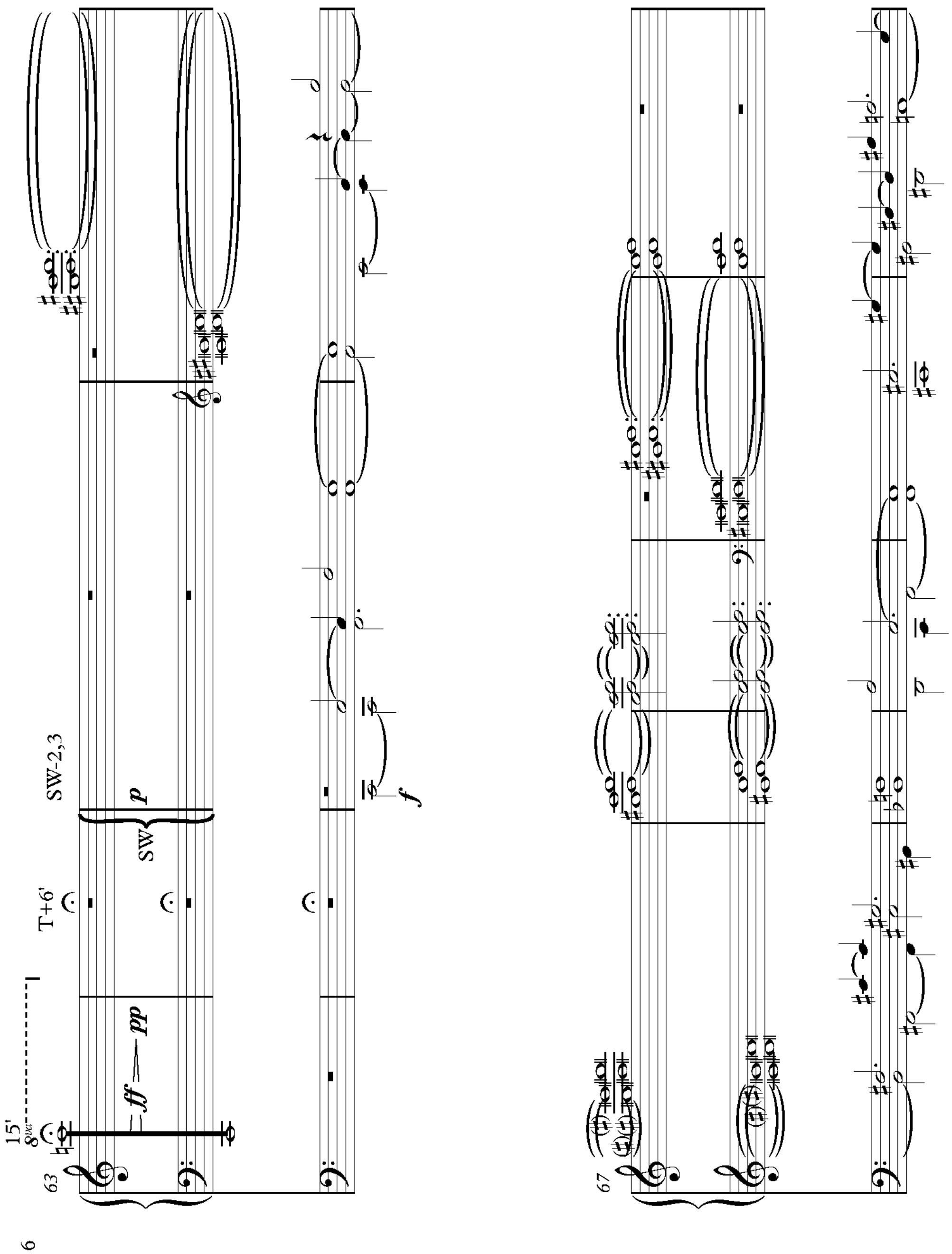


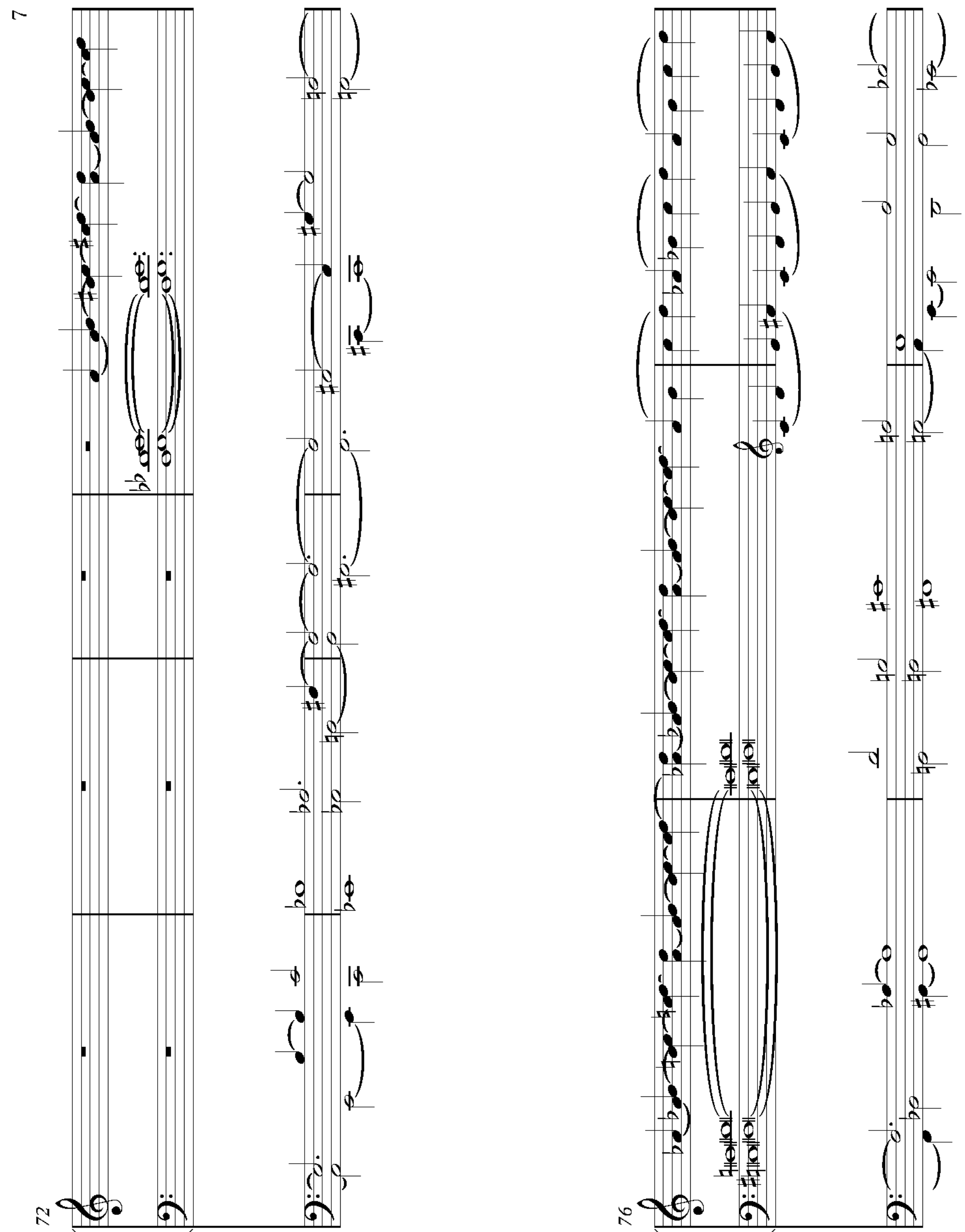

2
17
(8)
8va
T+2'
T
24
T+4'
3

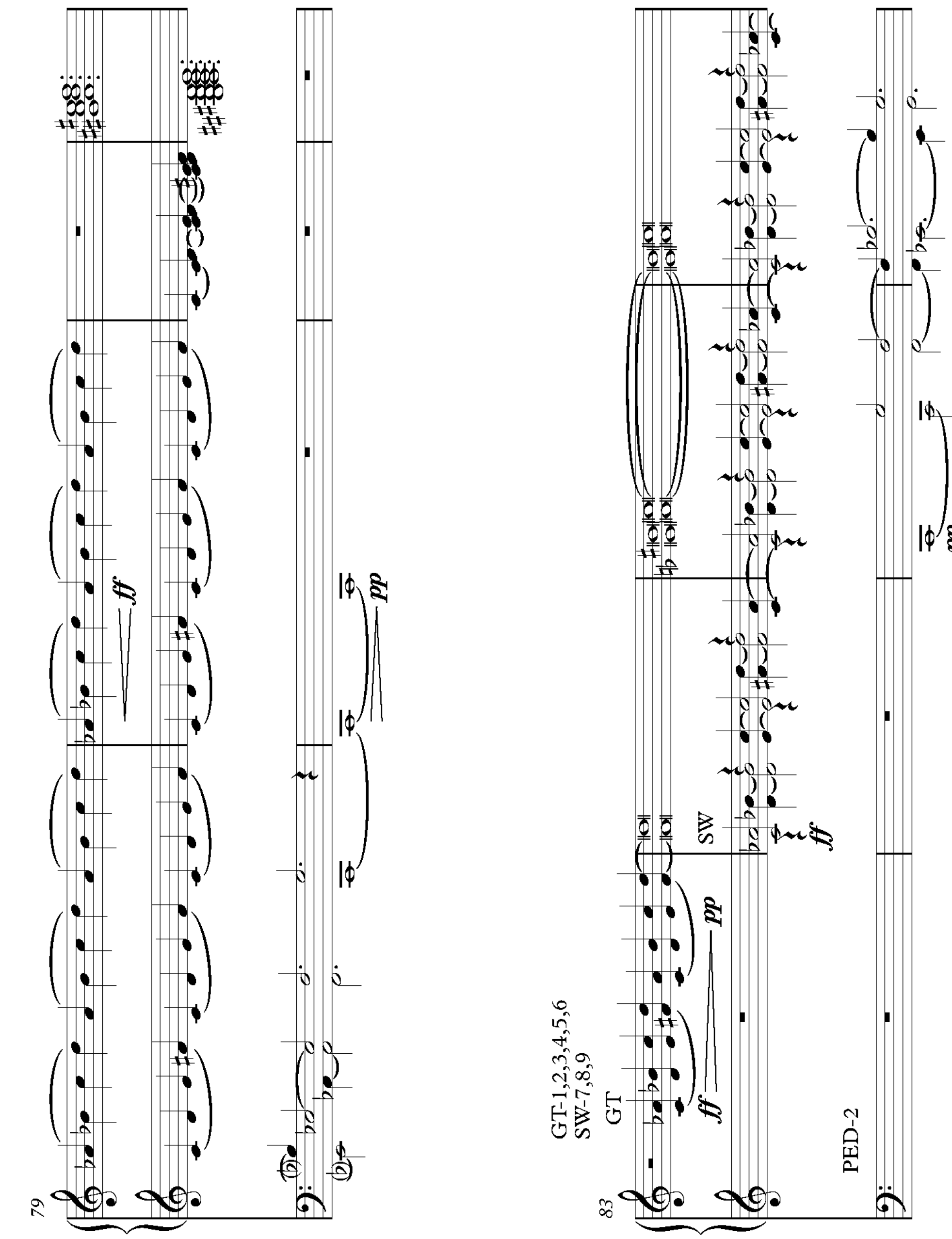

3
31
39
15'
8va
T+6'
SW
ff
pp
pp < ff

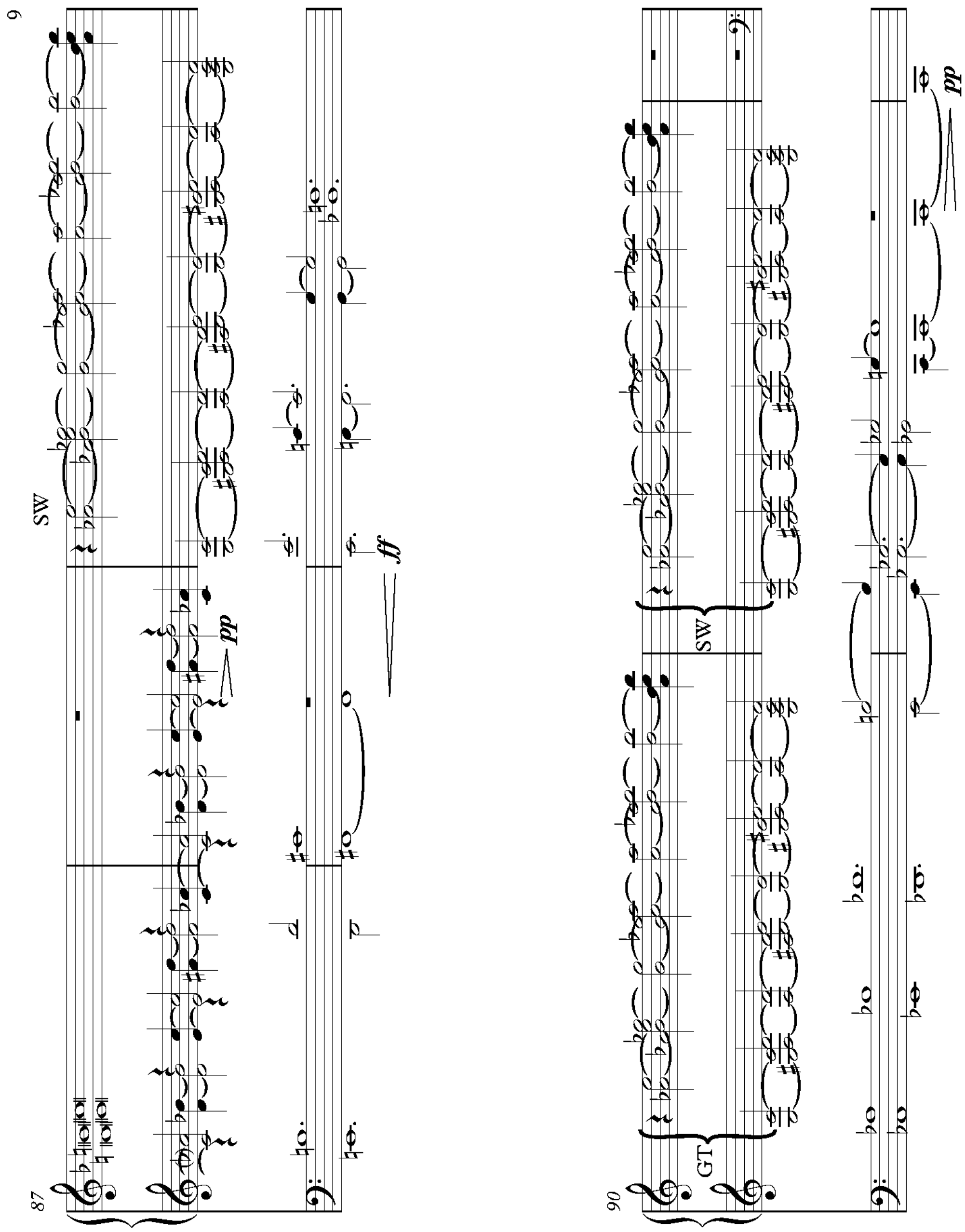

4
46
pp < ff
pp < ff
pp < ff
49
pp
ff
mp

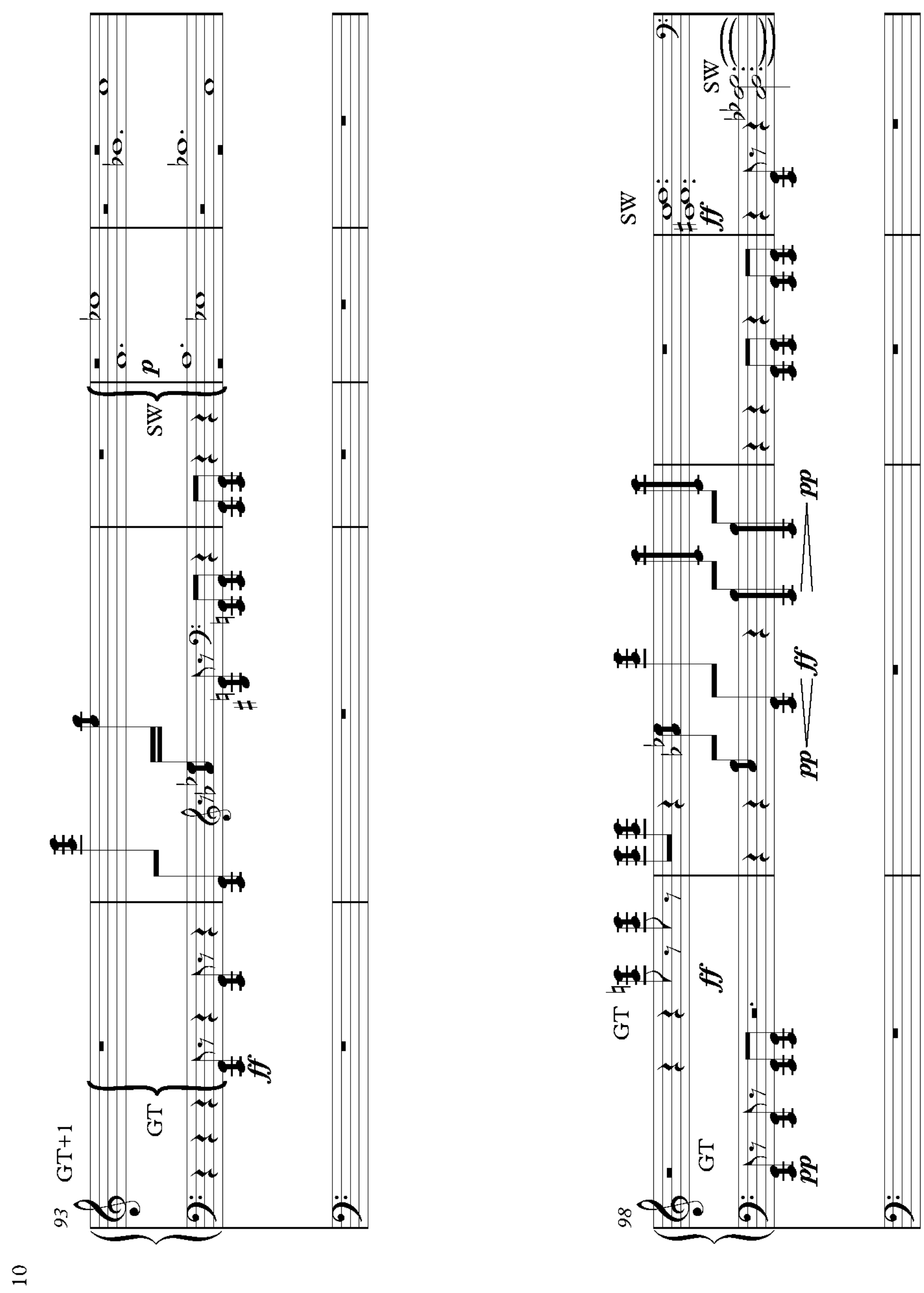


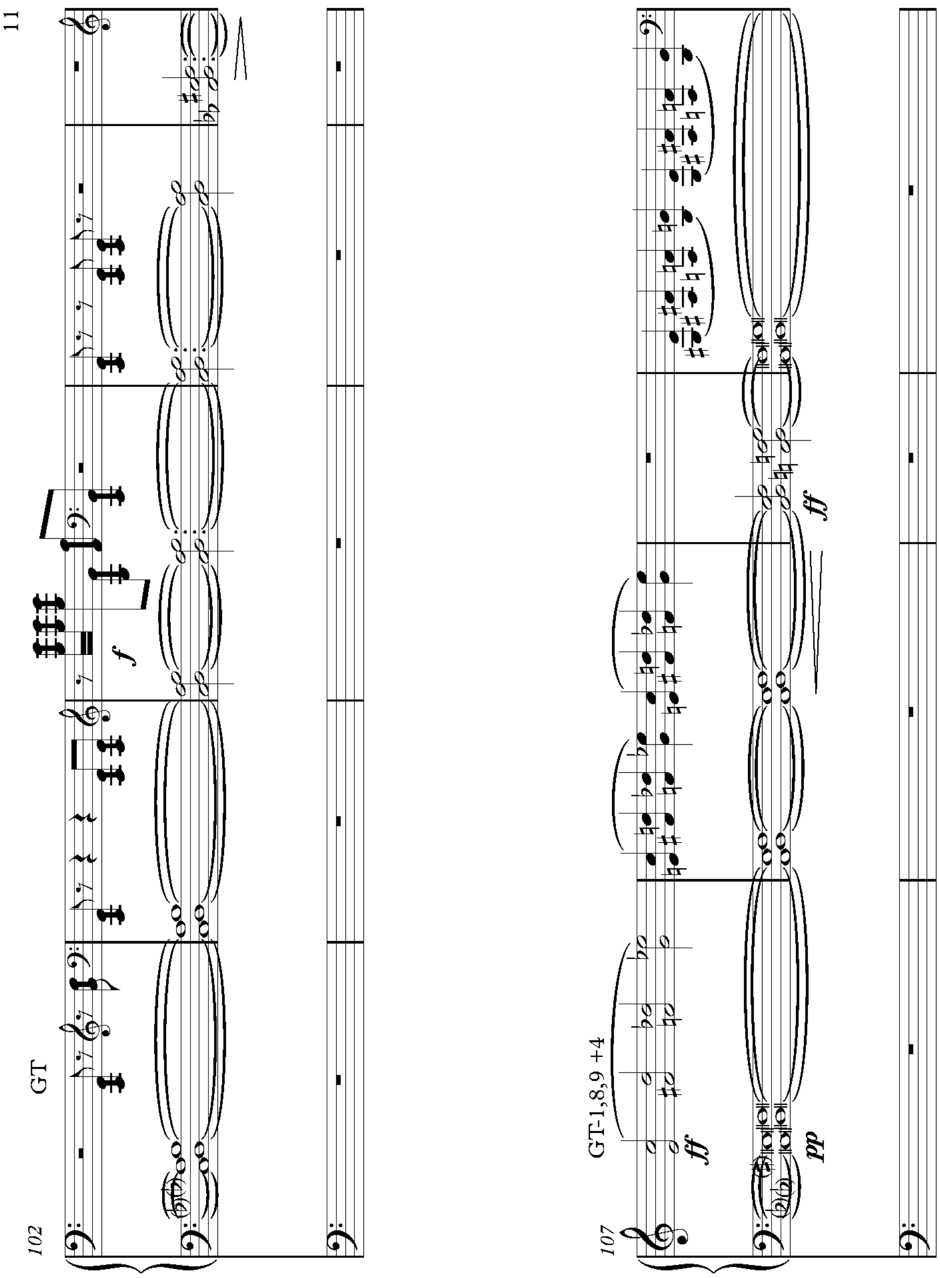

6
63
15'
8va
T+6'
SW-2,3
SW
ff
pp
p
f
67

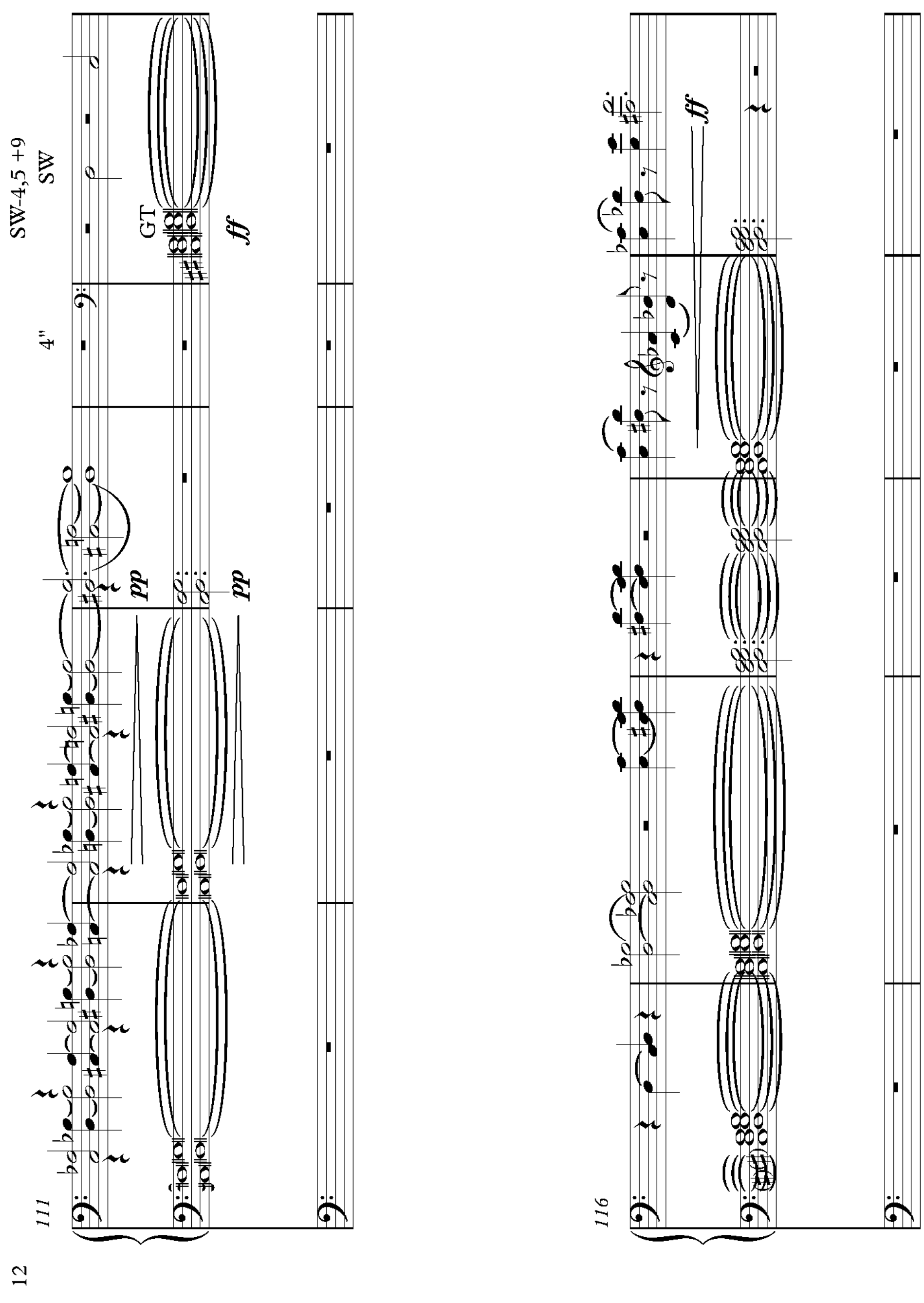


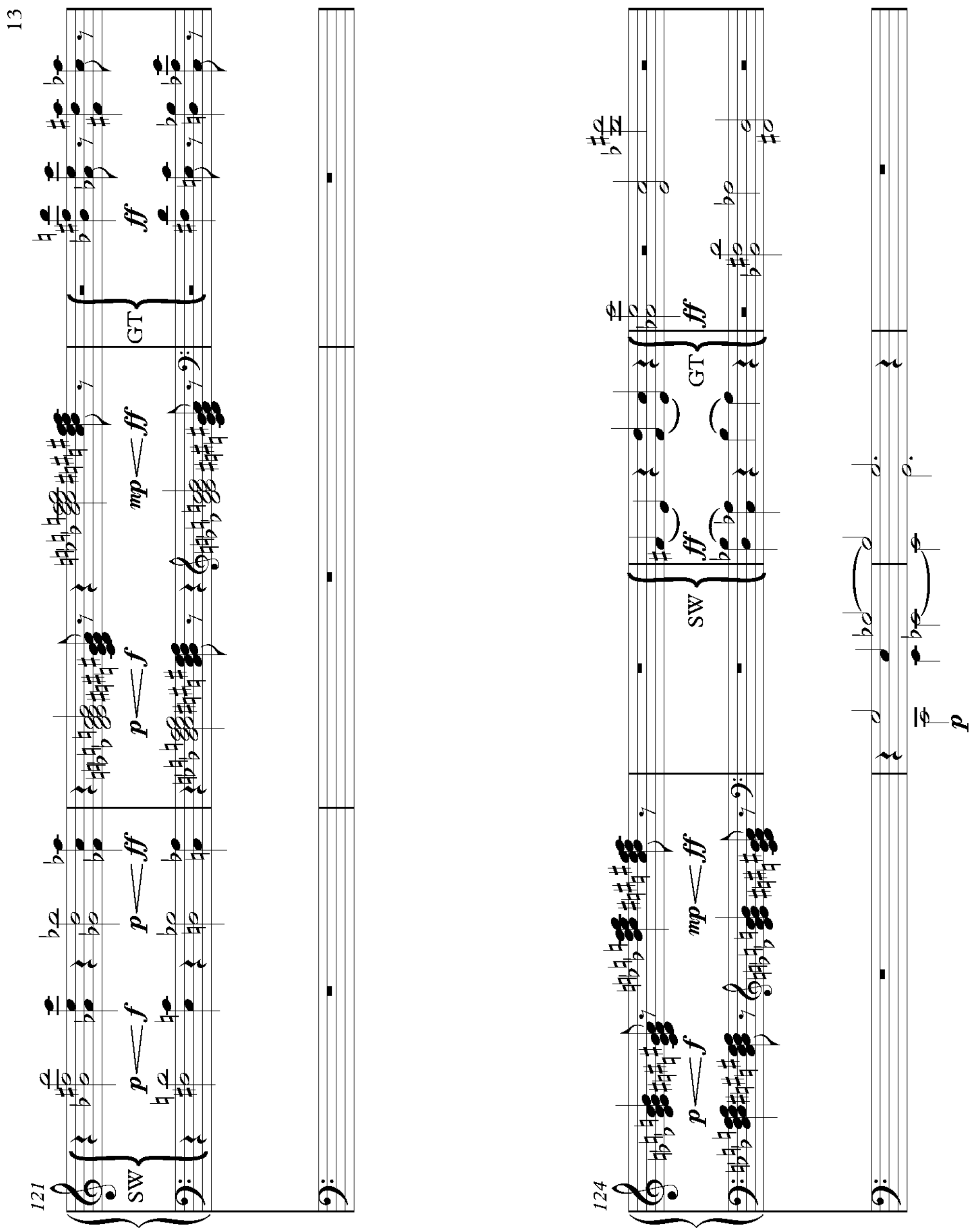

8
79
ff
pp
83
GT-1,2,3,4,5,6
SW-7,8,9
GT
ff
pp
SW
ff
PED-2
pp


87
SW
pp
ff
90
GT
SW
pp


10
93
GT+1
GT
SW
98
GT
SW


11
102
GT
f
107
GT-1,8,9 +4
ff
pp
ff


12
111
SW-4,5 +9
SW
4"
GT
pp
pp
ff
116
ff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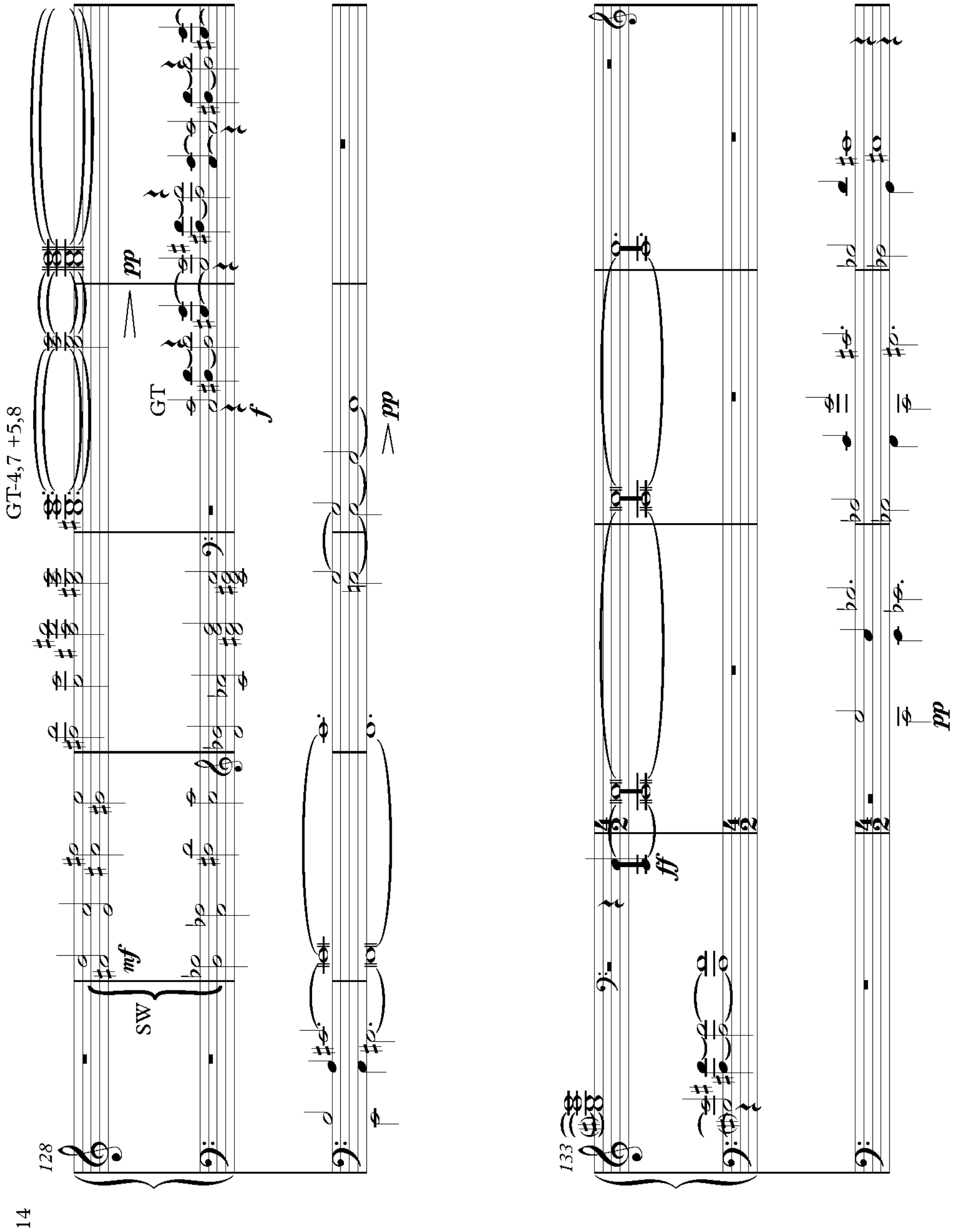
SW
GT
124
SW
GT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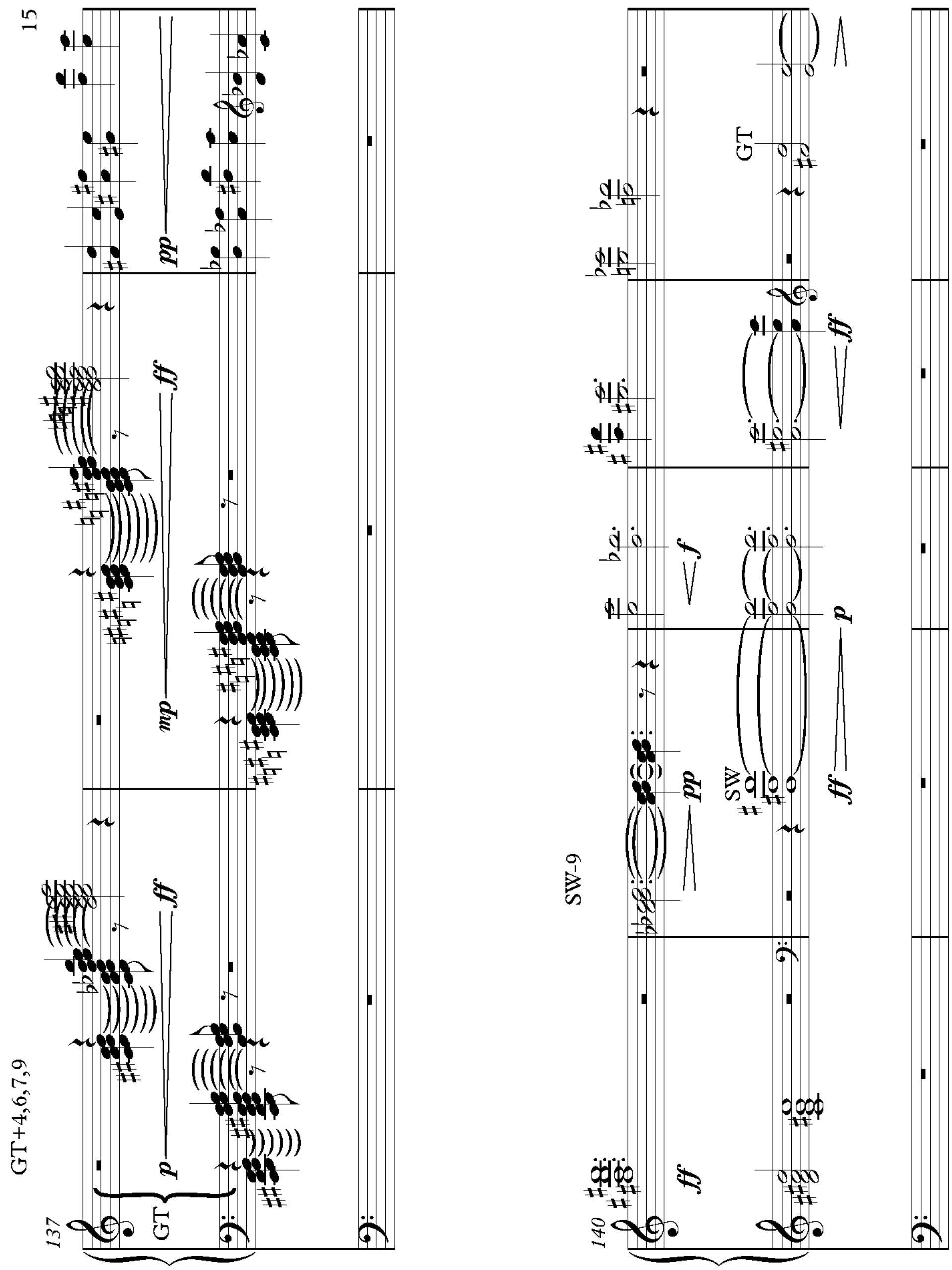
SW
mf
GT-4,7 +5,8
GT
f
pp
133
ff
pp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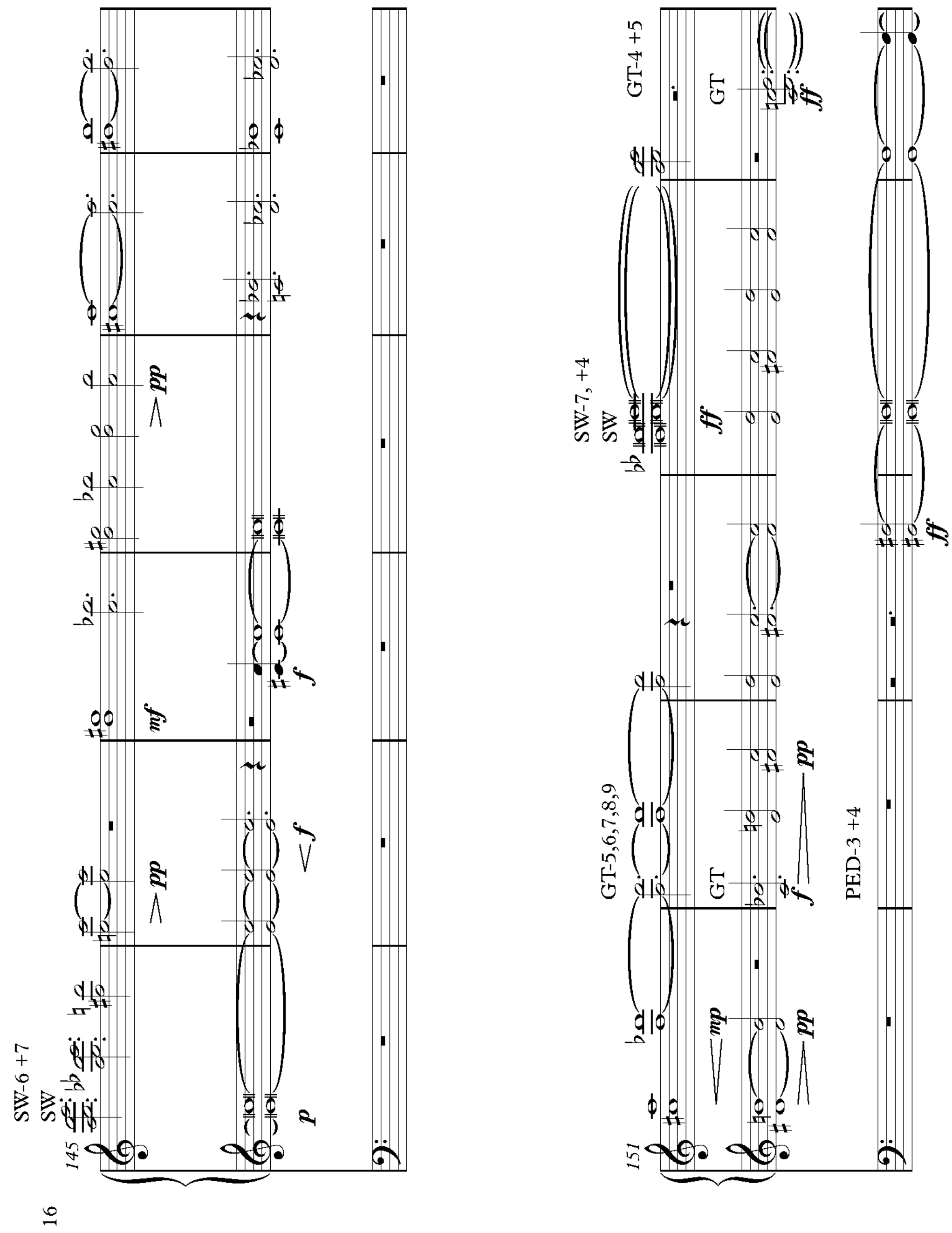
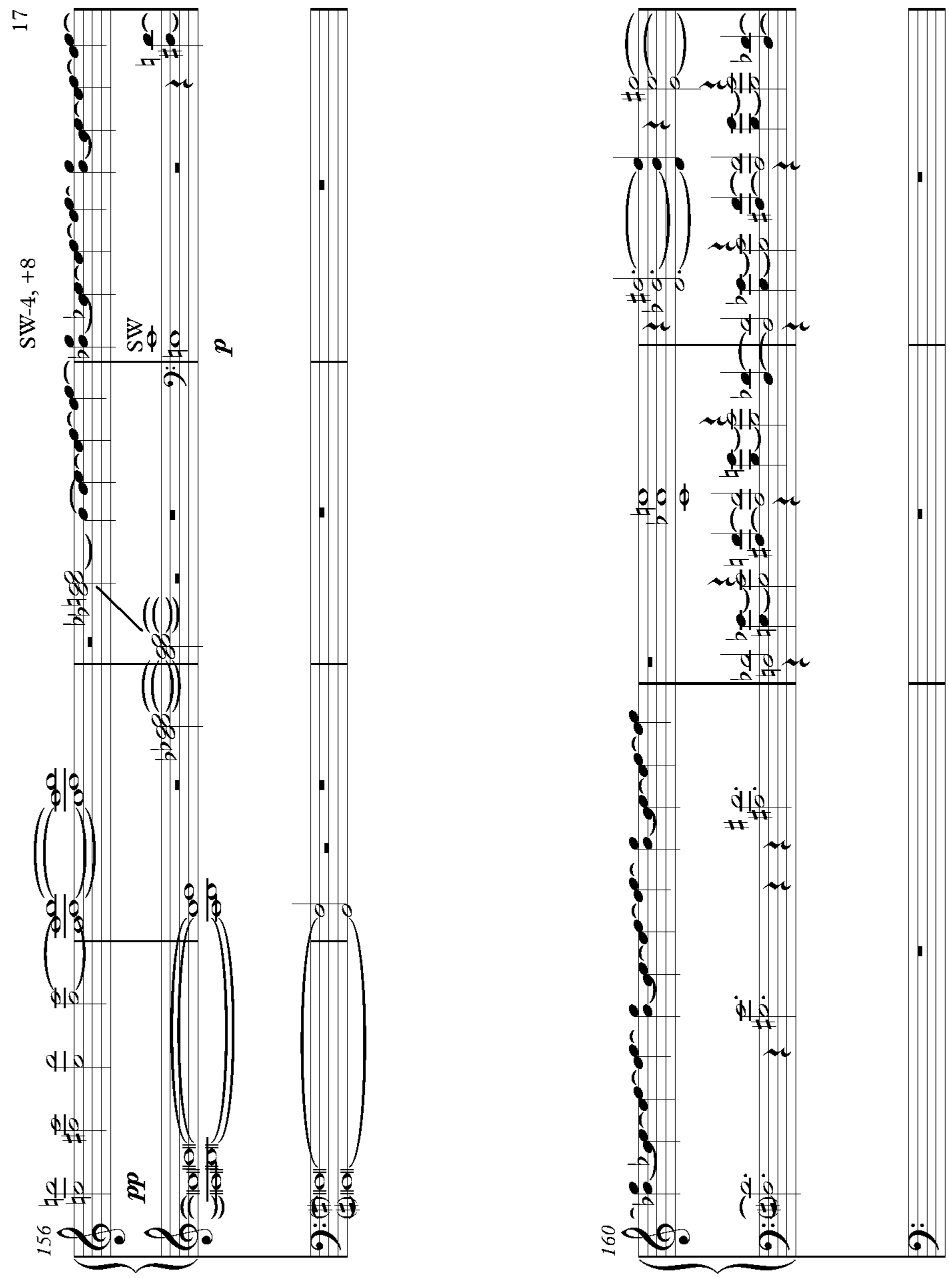
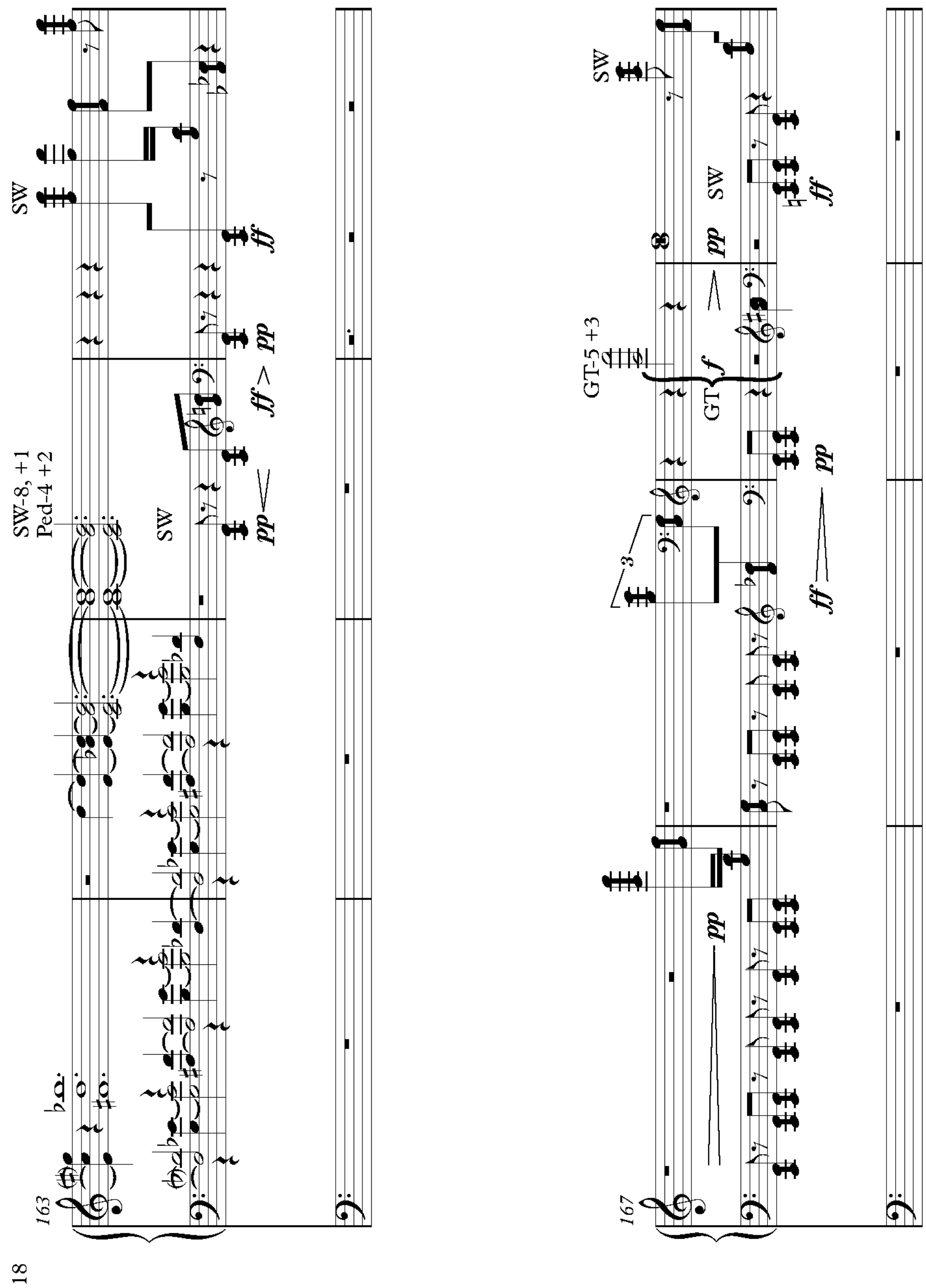
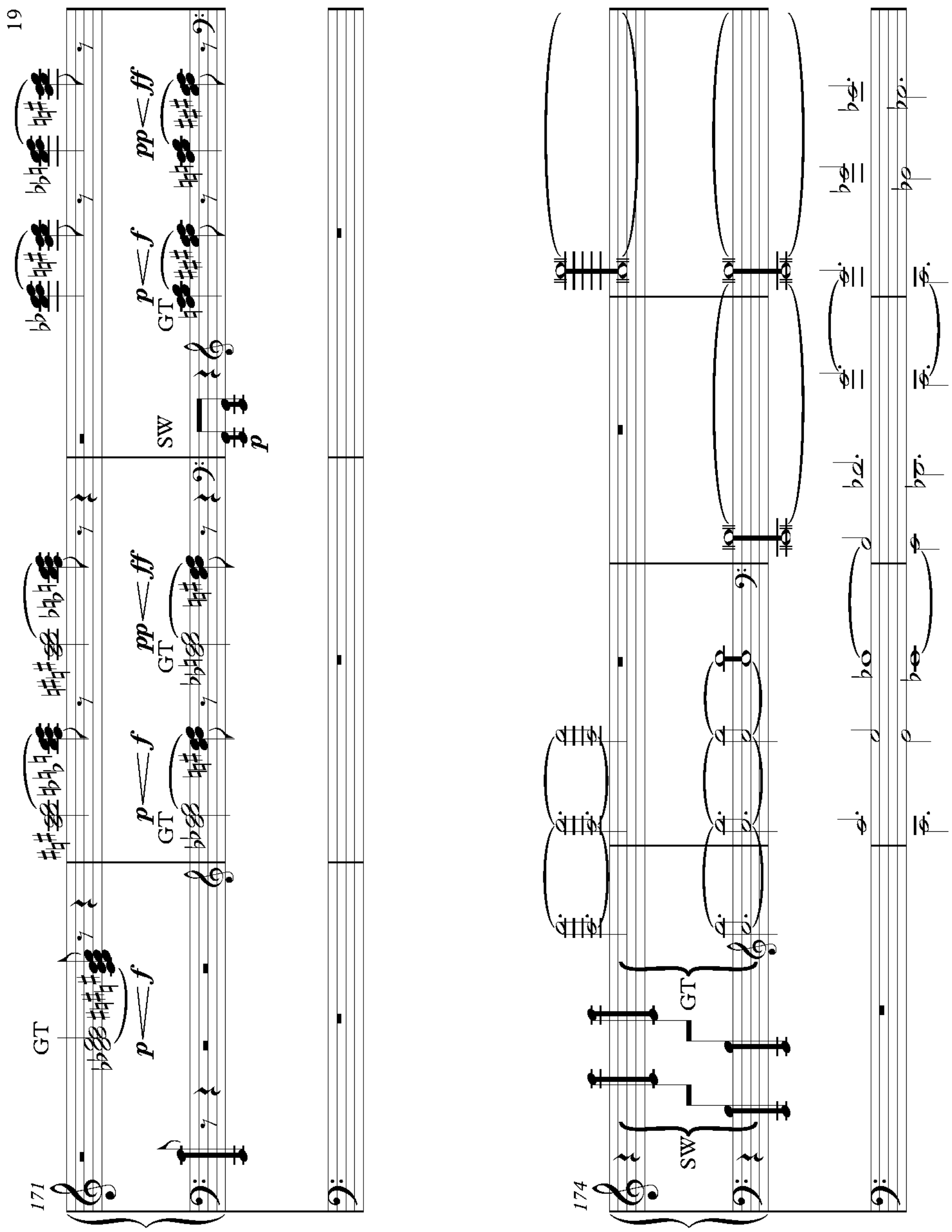
GT+4,6,7,9
GT
p
ff
mp
ff
pp
140
ff
SW-9
pp
SW
ff
p
f
ff
GT


16
145
SW-6 +7
SW
p
pp
f
mf
pp
151
GT-5,6,7,8,9
GT
mp
pp
f
pp
PED-3 +4
SW-7, +4
SW
ff
ff
GT-4 +5
GT
ff


17
SW-4, +8
SW
156
pp
p
160


18
163
SW-8, +1
Ped-4 +2
SW
167
GT-5 +3
GT
SW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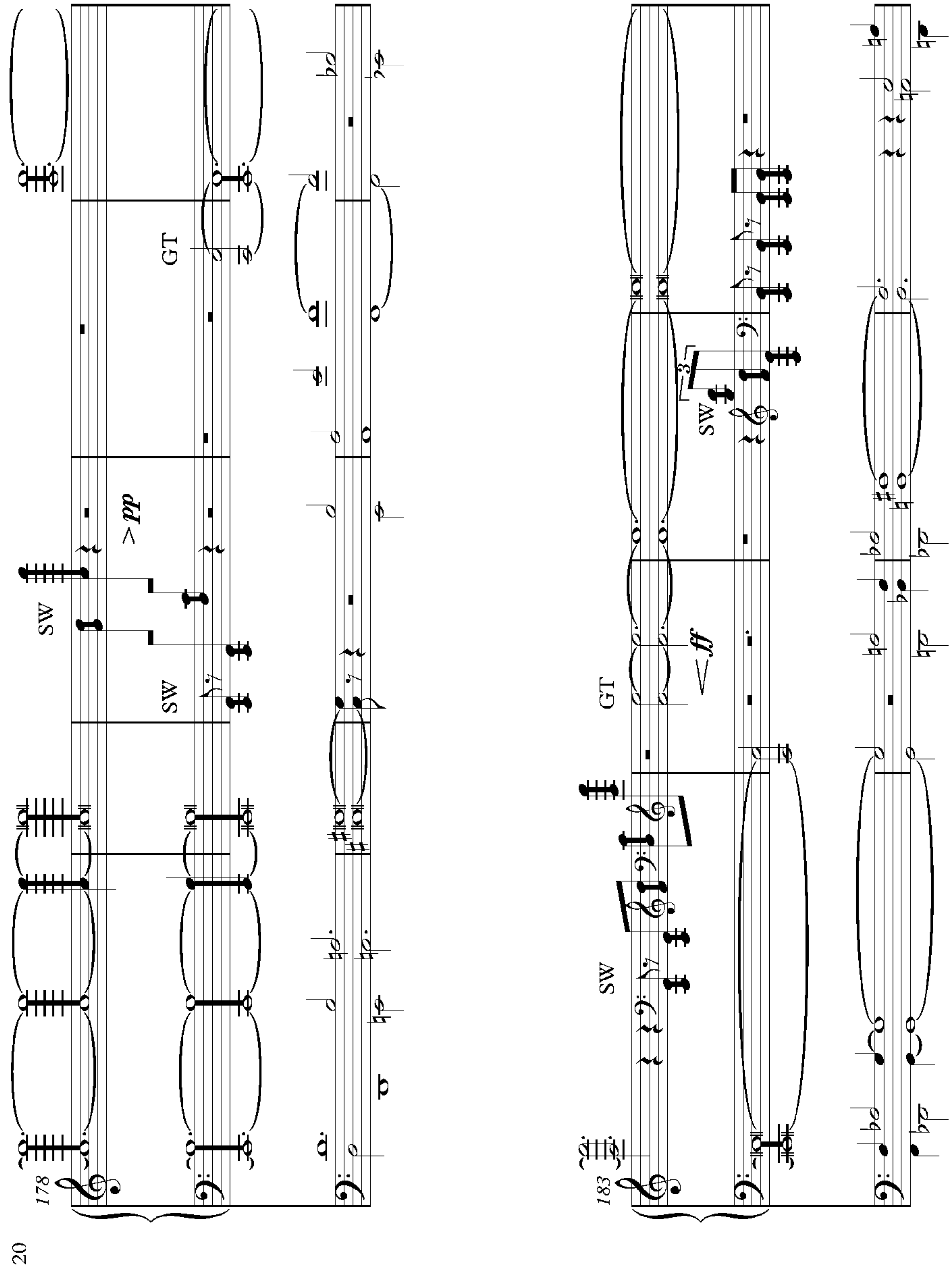
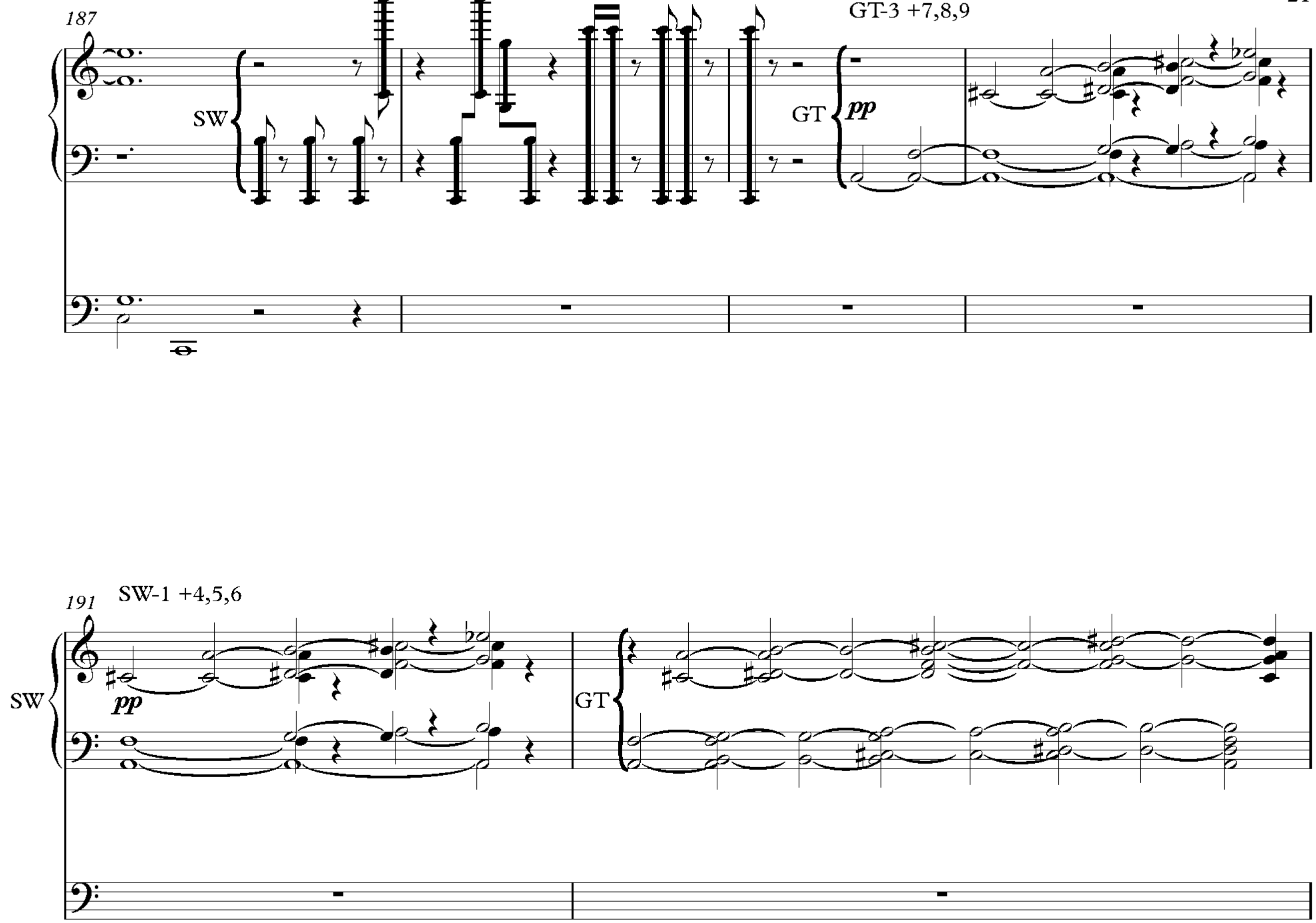
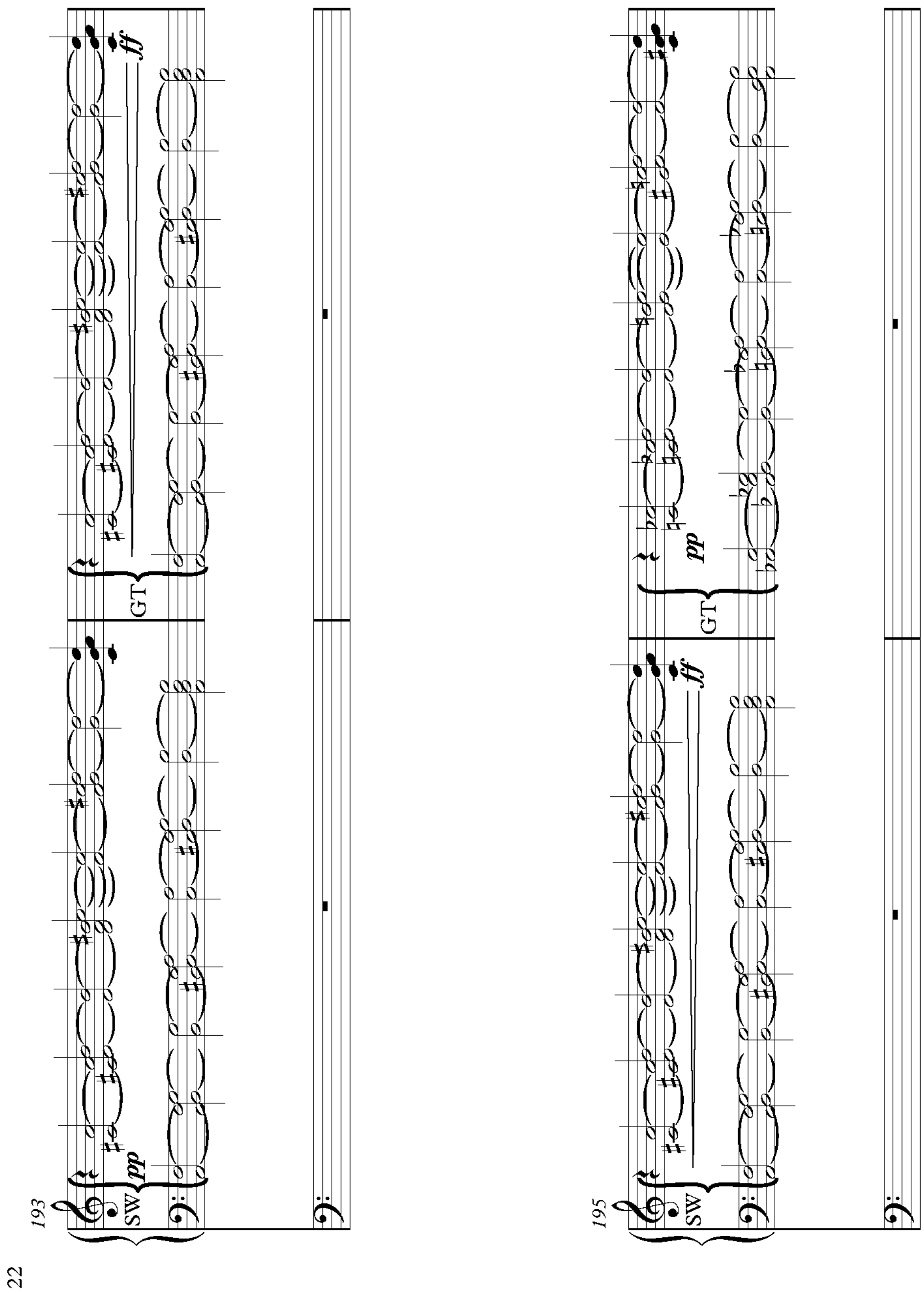
171
GT
p < f
pp < ff
SW
p
174
SW
GT


20
178
SW
SW
pp
GT
183
SW
GT
ff
SW
3


187
SW
GT-3 +7,8,9
GT
pp
191
SW-1 +4,5,6
SW
pp
GT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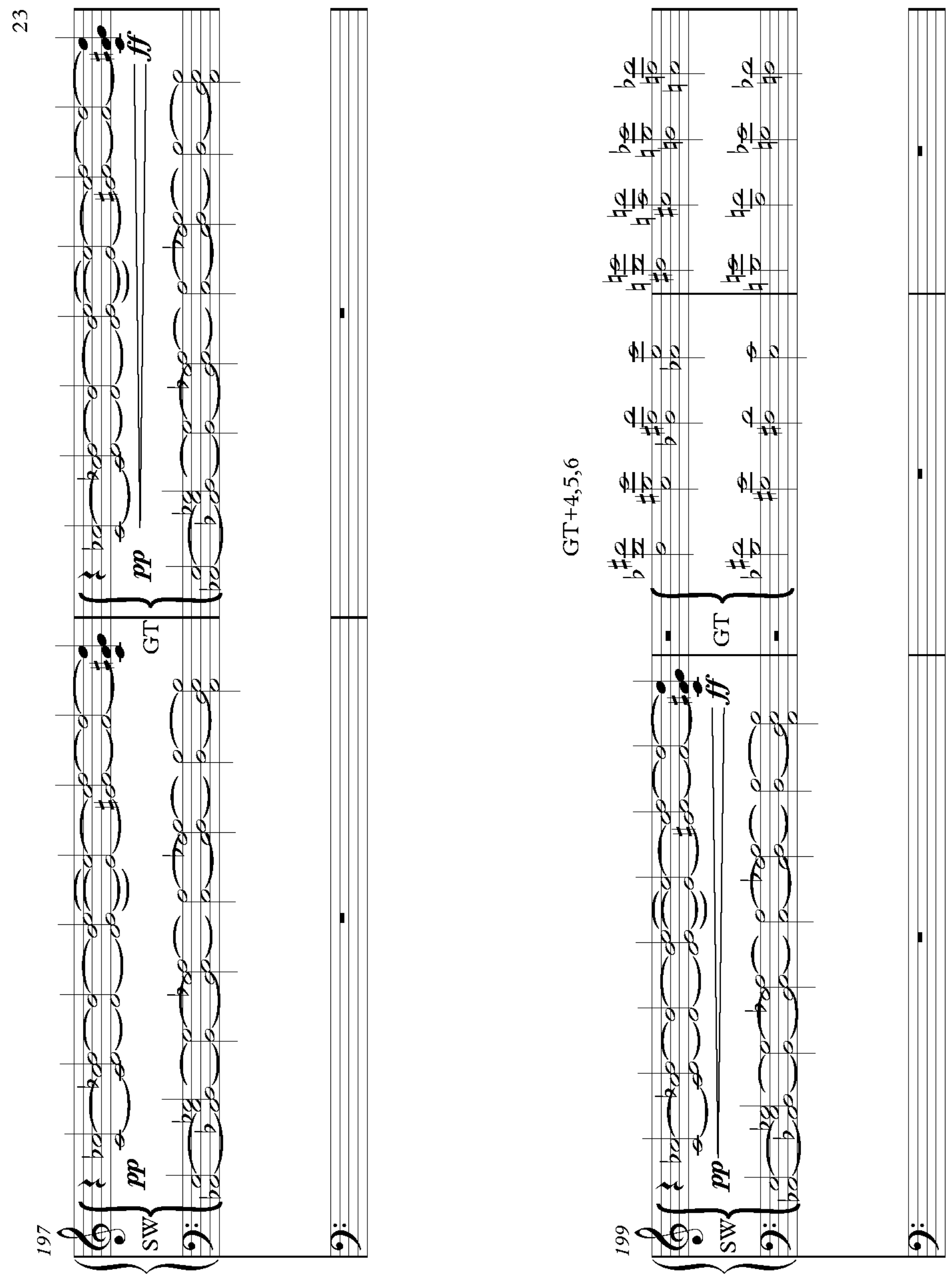
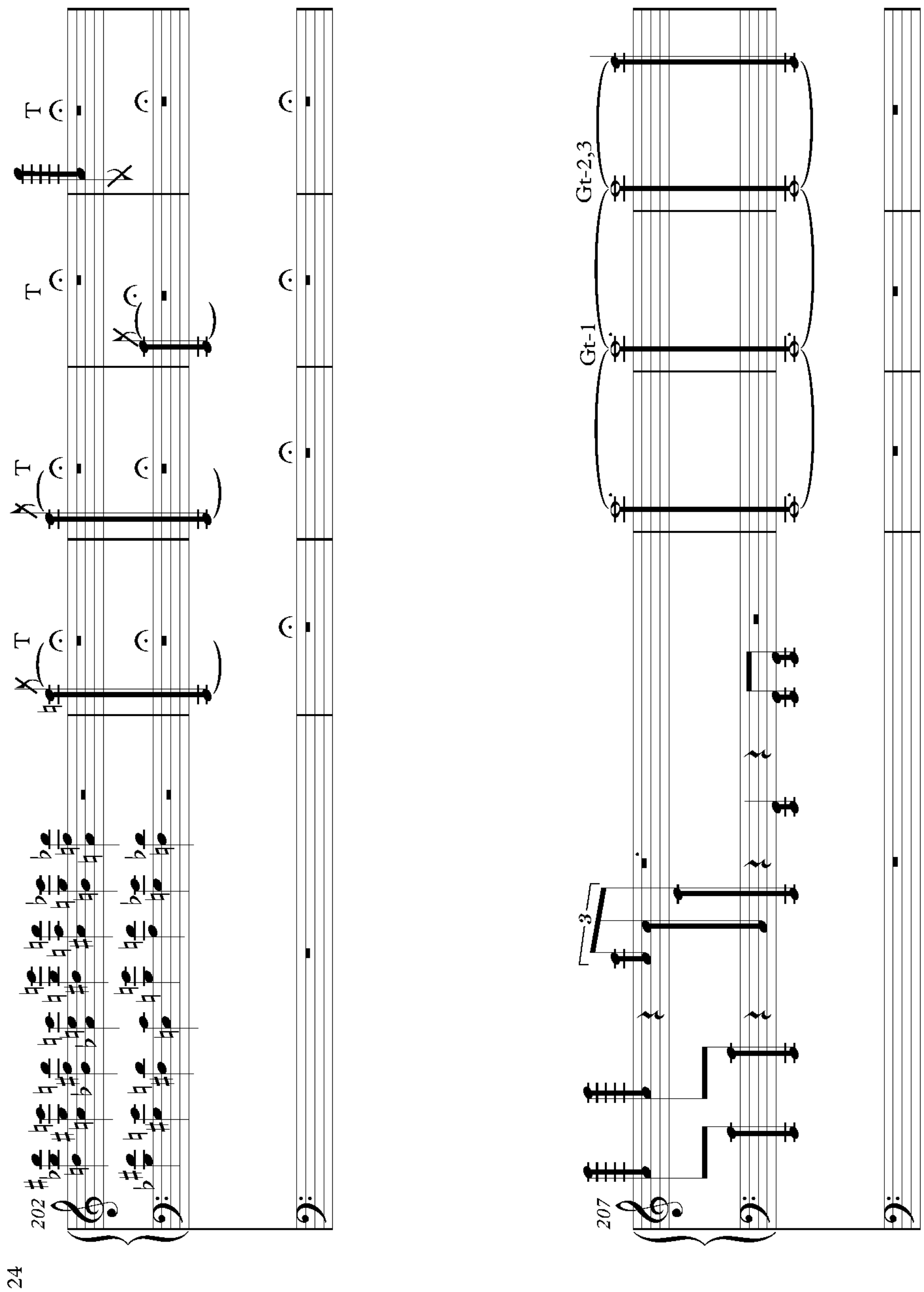
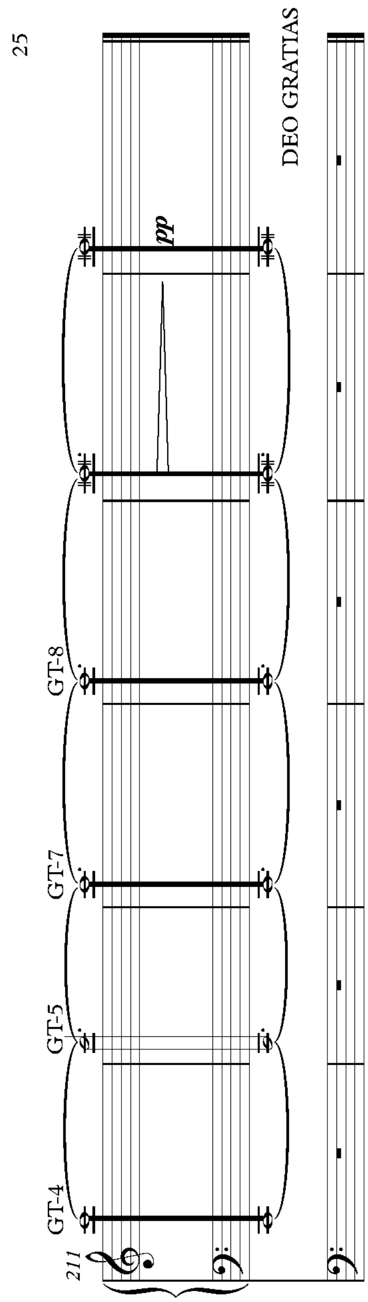
193
SW
GT
pp
ff
195


23
197
SW
pp
ff
GT
199
GT+4,5,6


24
202
T
T
T
T
207
3
Gt-1
Gt-2,3


25
DEO GRATIAS
211
GT-4
GT-5
GT-7
GT-8
pp

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