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A Diachronic Analysis of Harmonic Schemata in Jazz

Daniel Shanahan[1] & Yuri Broze[2]

School of Music, Ohio State University, USA
[1]shanahan.37@osu.edu, [2]broze.3@osu.edu

ABSTRACT

Jazz harmony relies heavily on a set of well-defined harmonic patterns that evolved gradually throughout the 20th century. While certain tonally-oriented progressions such as the "ii-V-I" appear to be nearly ubiquitous across time-periods, the jazz tradition also includes a notable departure from tonal harmony: the rise of modal jazz in the late 1950s. We aimed to systematically investigate the history of jazz composition by describing the evolution of chordal syntax, as well as the sort of organizational frameworks that might be described as harmonic schemata.

In this study, we empirically describe the most common chords and chord motions of the jazz canon, and trace their evolution over time. Additionally, we describe an attempt to account for one particularly well-known compositional schema: the so-called "rhythm changes." In so doing, we make use of a recently compiled database of harmonic progressions for more than 1,160 jazz standards, encoded into the Humdrum "kern" format (Huron 1995).

The present study provides details of corpus validation, and presents an initial descriptive characterization of the data set. Furthermore, we present evidence consistent with the hypothesis that chord sequences using tonal harmonic syntax became progressively less common from 1925 to 1970. Finally, we characterize the decline in popularity of one harmonic schema: the so-called "rhythm changes."

I. INTRODUCTION

The history of jazz can be analyzed through a number of different perspectives. First, one could analyze the evolution of improvisation, allowing for an exploration of the tonal language that so frequently defines the idiom. Alternatively, one could examine the nature of arranging, plotting the rise of formal big band arrangements from the spontaneous style of the New Orleans marching bands. The current study, however, opts for a third path: the analysis of harmonic progressions in jazz or, more precisely, those in jazz standards appearing in fake books. By creating an electronic database of these jazz progressions, one would be able to chart the compositional trends defining the "jazz standard." Moreover, such a corpus could facilitate an empirically-grounded view of popular music in the 20th century.

A score-based study of a genre as detached from the written page as jazz presents several inherent difficulties. Most importantly, the notion of an authoritative version or score is not easily defined. For example, a Charlie Parker composition such as "Confirmation" or "Donna Lee" has likely been performed and recorded innumerable times since its conception. A recording of a tune with Bud Powell as pianist might employ significantly different harmonizations than one with Thelonious Monk. It would be difficult to describe one recording as being more authoritative than the other without introducing personal or theoretical bias.

The harmonic language of jazz is fluid and living, characterized by the continual introduction of reharmonizations that may be dependent upon the harmonic clichés at the time of performance. As such, a transcription of a single recording might not adequately capture the spirit of the composition. While D'Clerq and Temperley (2011) were easily able to identify definitive versions of rock and pop recordings, this tactic would not necessarily translate well to the jazz idiom. Aside from big band arrangements, the dependence on an authoritative score has often been secondary in jazz music.

Nonetheless, it is possible to focus specifically on the form of a composition most likely to play an active role in the continuation of the jazz tradition: fake books. While a systematic study of fake books would not necessarily be able to account for foreground harmonic gestures with complete accuracy, it might still allow for a study of certain large-scale harmonic trends throughout the twentieth century.

In the present study, we describe the compilation and verification of an electronically-encoded database of jazz chord changes, principally representing compositions recorded between 1925 and 1970. We then set out to characterize its contents. We conjectured that the modal jazz movement arising during the late 1950s would result in certain observable changes in the frequency of tonally-inspired chord progressions. Specifically, we tested the hypothesis that root progressions of a perfect fourth (P4) would become less common from the 1920s to the 1970s.

To anticipate our results, we found that certain progressions (such as those resembling "V-I" of "ii-V" types of motion) do indeed exhibit a decrease in prevalence over this period. However, we did not detect any decrease in the prevalence of "V/ii-ii" or "V/V-V" types of motion.

Finally, we describe an attempt chart the popularity of one harmonic schemata: the so-called "rhythm changes."

II. ASSEMBLY OF THE DATABASE

A. The Apocryphal Nature of the Fake Book

Fake books themselves are somewhat difficult to provide a definitive account for, in part because they have been illegal for most of their history. Kernfeld (2006) writes that the first widely traded illegal jazz sheet music can be traced back to 1929. Fake books did not, however, gain widespread popularity until 1942, when radio programmer George Goodwin formed a company known as "Tune-Dex." Goodwin's product was a collection of lyrics, melodies, and harmonic progressions to some 25,000 songs, inscribed onto individual index cards. These cards were marketed to working jazz instrumentalists on the emerging "cocktail" circuit.

Unfortunately, this system was susceptible to piracy and bootlegging. As a result, there were multiple Federal investigations throughout the 1950s, resulting in the eventual closure

of the company. For the majority of working jazz musicians, there were relatively few options but to transcribe from recordings. When the "Real Book" was collated in the mid-1970s, it provided performers with a canon, albeit one of illicit and somewhat apocryphal origin. By creating this canon, however, the genre was, in many ways, limited to the select few tunes that were able to be easily performed. Any study using such collections must take this into account.

B. Assembly

While jazz musicians of previous generations made use of paper copies of lead sheets, current jazz musicians have access to Internet communities to exchange notated music. We identified an online forum over which jazz musicians actively exchange electronically-encoded sheet music (http://irealb.com/forums). This site allows users to trade pieces that have been encoded into a proprietary format for use with desktop and smartphone applications. From these forums, we collected 1,200 individually encoded lead sheets, each of which specifies a title, composer, key signature, time signature, chords, durations, and indicators of form (such as section labels, repeats, and codas).

In assembling a database around this canon, we must acknowledge that it represents a considerable bias toward those pieces which remain in active use as part of the jazz canon. As such, it represents a mere fraction of the jazz compositions present throughout the 20th century, and it potentially reflects several biases introduced by members of the jazz community (For instance, Thelonious Monk is the most represented composer in this collection, while works by other, arguably more influential, composers such as Duke Ellington are less common). Additionally, the database represents a relatively brief timeframe, including few pieces composed after the original collation of many of the fake books in the mid-1970s.

In order to use this corpus for hypothesis testing, it was first necessary to convert the bulletin board-derived database into a Humdrum-like format (Huron, 1995). We then employed a series of automated Bash and AWK scripts to extract and subsequently re-encode the rhythmic and harmonic information. This process relied on reverse-engineering the specification; the conversion process was imperfect, and not without translation errors. Of the 1,200 lead sheets originally collected, 40 were lost to gross conversion errors, leaving us with 1,160 pieces. Following this initial step, we manually entered key signatures, dates of first recording, and composer information. Various translational errors were then manually corrected.

C. Composers Represented

The database contains the works of 458 individual composers. Of these, Thelonious Monk is the most frequently represented, with 44 of his works being included in the corpus. This is followed by Richard Rodgers and Cole Porter, with 37 and 31 compositions, respectively. Table 2 lists the 20 most represented composers in the corpus. One could interpret this distribution as representative of current jazz practice.

D. Validation

In order to validate the kern-encoded database, we randomly sampled 250 individual chords from the 1,160 pieces, and compared them against a selection of twenty published fake books (seen in Table 1). These fake books themselves do not necessarily contain identical harmonic interpretations, but nonetheless might be considered to be reflective of musical practice. We therefore considered all fake books to have the same *a priori* legitimacy. If a Humdrum-encoded score was consistent with that found in any of these fake books, it was considered to be valid.

Table 1: List of the 20 most represented composers in the database. The corpus reflects not a systematic sample, but instead was compiled by an online community of jazz musicians and enthusiasts. Hence, the distribution of composers represented could be taken as being representative of current jazz practice.

Composer	Pieces Represented
Thelonious Monk	44
Richard Rodgers	37
Cole Porter	31
Wayne Shorter	29
George Gershwin	28
Charlie Parker	25
Duke Ellington	22
Irving Berlin	22
Jerome Kern	20
John Coltrane	20
Antonio Carlos Jobim	20
Harold Arlen	19
Jimmy van Heusen	17
Miles Davis	14
Herbie Hancock	13
Chick Corea	13
Bill Evans	12
Horace Silver	11
Hoagy Carmichael	11
Joe Henderson	11

During the validation process, we identified five possible errors in a chord's encoding:

1) Correct chord root (relative to the published key) and quality (major, minor, or dominant, ignoring extensions).

2) Reharmonizations in which the spellings of two chords were similar, but there was a slight disparity in chord notation (as discussed in Levine, 1995, 259). One such example would be a C7sus4/G being notated in one publication, but a G-7(11) in another. When these errors were examined, it was apparent that they were not encoding errors, but rather respellings or reharmonizations of the progressions published in the fake books. Another such example could is seen when a measure containing one dominant chord would be changed to have an applied dominant (such as V/V) on the first beat, and the dominant chord on the third beat.

3) Typical jazz reharmonizations, such as the V being replaced with a "ii-V" or a tritone substitution (as discussed in Levine, 1995 and Felts, 2002).

Table 2: List of Fake books consulted for corpus validation

1. Anthologie Des Grilles De Jazz
2. Real Book Of Blues
3. Cuban Fake Book
4. Colorado Cookbook
5. Bill Evans Fake Book
6. Hal Leonard Real Jazz Book
7. Library of Musicians Jazz
8. Jazz Fake Book
9. Jazz LTD
10. Latin Real Book
11. New Real Book 1
12. New Real Book 2
13. New Real Book 3
14. Real Book 1
15. Real Book 2
16. Real Book 3
17. The Slick Book
18. Standards Real Book
19. The Book
20. The Other Book

4) Encoding errors in which the root or quality could not feasibly represent jazz practice.

5) Instances in which chords were deleted or omitted entirely.

By choosing these classifications instead of a simple binary judgment of correctness, it was possible to characterize the specific nature of the errors present. This allowed us to form more refined expectations about the uncertainties inherent in our database. This knowledge could then inform the reliability of different types of corpus-based analyses.

Of the 250 chords sampled for validation, 37 were from pieces not included in the 20 fake books. These selections were omitted from the validation, leaving 213 chords for analysis. Of these, we identified 188 correct matches (88.2%), and 12 reharmonizations (5.6%). This indicates reasonably high agreement between the corpus and published sources, but also that subjective reinterpretation has apparently shaped the corpus to some extent. That is, broad-scale musical structures appear to be largely intact. Additionally, there were 8 wrong-chord errors (3.8%), and 5 chord omissions (2.3%). These types of error would likely represent random noise, and loss of analytical power, depending on the type of study conducted. Considering chord-mismatch errors alone, a 95% confidence interval of the error rate was calculated to be between 1.6% to 7.3%. We will continue to manually correct encoding errors as they are discovered.

We interpreted the results of this validation to have a number of implications for corpus studies. For instance, results from diachronic studies (such as the present study) must be taken with caution when examining such phenomena regarding "progressive association" and "deformation" of foreground schemata (to invoke Gjerdingen's terminology, 1986, 36). In this context, information on specific chords would not be as reliable as a study of the evolution of higher-level harmonic structures.

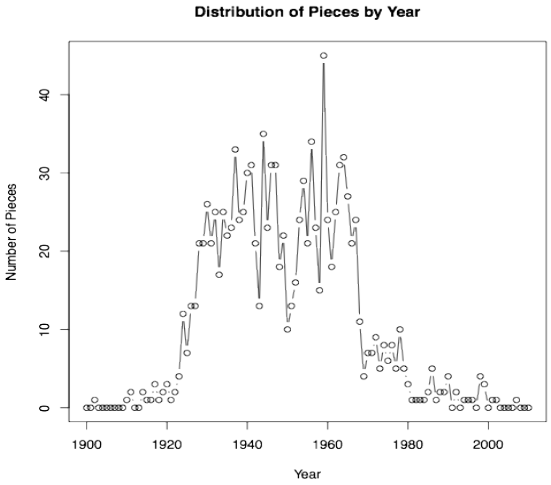

Figure 1: Distribution of total number of pieces represented in the database by year. Because the corpus was derived from an online community's assembled canon, the pieces were not systematically sampled. Nonetheless, there appears to be a relatively uniform distribution of pieces from 1925 until 1970. Our

E. Years Represented

As mentioned above, the majority of pieces fall within the five decade span from 1920 to 1970 (see Figure 1). As a result, a number of subgenres within jazz are somewhat underrepresented. For example, the New Orleans style of jazz is barely present at all. As a result, diachronic studies will have the most legitimacy when focusing on this relatively short timeframe. Nevertheless, this span allows to account for changes in jazz harmonic practice between the decade of its greatest popular success (the 1920s) and the rise of so-called "jazz-rock fusion" in the 1970s. One might also be able to describe changes in compositional trends between the pre-War and post-War era.

As part of our preliminary exploratory analysis of the corpus, we wished to characterize the degree to which it might be used to track diachronic trends in music. Figure 2 depicts the fractions of chords that were encoded as major, dominant, minor seventh, or minor chords, plotted against the year in which a given piece was recorded. On each plot, a trace of the relative number of pieces per year is provided as an indicator of the precision of the estimates. For each chord quality, the estimated fractions have much more year-to-year consistency between 1920 and 1970, as would be expected given the distribution of pieces across time. Visual inspection of these plots further substantiates the view that inferential tests would likely only be reliable within this window.

F. Exploratory Characterization

We conducted a series of exploratory studies into diachronic changes in chord use within the jazz idiom. Because of the role harmonic reinterpretation has played in the development of the jazz canon, we decided to focus on the most basic representation of chords. We characterized each chord as belonging to one of the following categories: major, minor, minor 7^{th} (including b5 varieties), dominant, augmented, or diminished. Of the 45,511 chords in the dataset, 18640 (41.0%) are dominant chords, 12020 (26.4%) are minor 7^{th} chords, and 10427 (22.9%) are major chords.

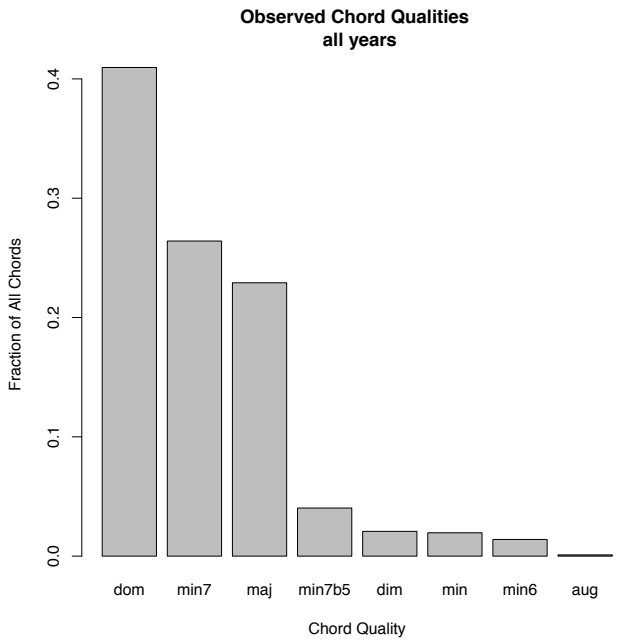

Figure 2: Observed Chord Qualities in the Database (represented as a fraction). Dominant chords the most common found, followed by minor 7th and major chords.

The three most common chord types were the major chord, the dominant chord, and the minor 7th chord. For each of these, we plotted their frequency of occurrence as a fraction of all chord types, from 1925 until 1970. The results are plotted in figures 3, 4, and 5. For each chord type, we checked for diachronic trends by fitting linear models to the data. 95% confidence intervals were constructed around the mean fractions of occurrence, here plotted as red lines.

In a post hoc statistical test, we tested whether there were significant trends to be found in any of the three chord qualities' frequency. While major chords and dominant chords did not reveal statistically significant trends (with *p*-values of . 93 and .21, respectively), we did find that minor 7th chords exhibited a statistically significant upward trend ($t_{44} = 2.606$, $p = 0.012$). It would therefore appear that minor seventh chords become progressively more plentiful, although the effect size is somewhat small.

One might interpret this change in chord quality distribution to reflect the introduction of "modal jazz." In modal jazz music, musicians rejected traditional bebop idioms (which were themselves derived from popular music, show tunes, and swing) in favor of free improvisations on certain scales. Of these, the Dorian mode, which might be most associated with minor 7 chords, was particularly widely used (Levine 1995, Pease and Pullig 2001).

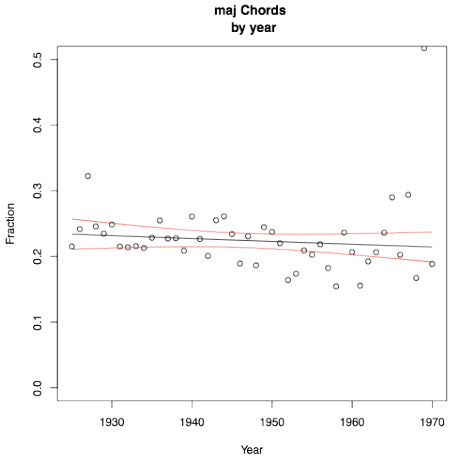

Figure 3: Use of major chords between the 1920s and 1970s (represented as a fraction of annual total). Bands correspond to a 95% confidence interval around the mean. There is no significant trend present.

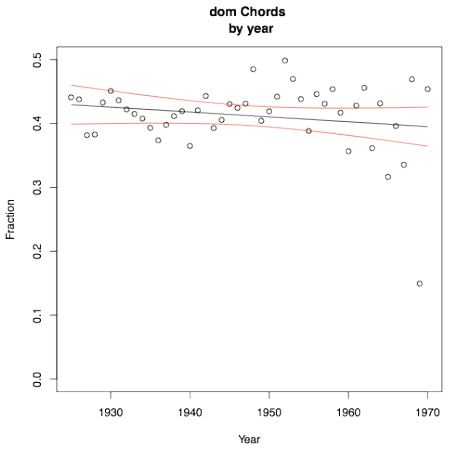

Figure 4: The usage of dominant chords between the 1920s and 1970s (represented as a fraction of annual usage). Bands correspond to a 95% confidence interval around the mean. There is no significant trend present.

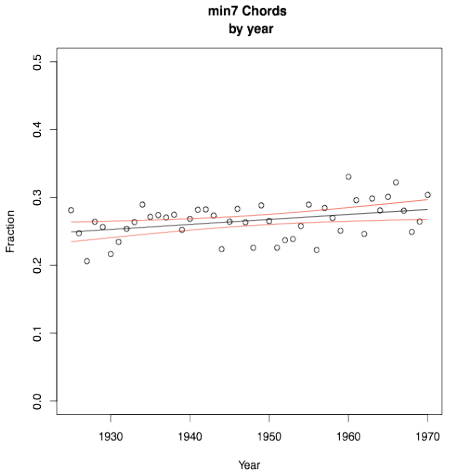

Figure 5: The usage of minor seventh chords between the 1920s and 1970s (represented as a fraction of annual usage). Bands correspond to a 95% confidence interval around the mean. A post hoc statistical test revealed a statistically significant upward trend ($t_{44} = 2.606$, $p = .012$).

G. Chord Progressions

After having described the frequency with which individual chords occur in the corpus, we set out to describe the distribution of two-chord pairs, or 2-grams. Because jazz harmony tends to make extensive use of applied dominants and often features fluctuating tonal centers, it is difficult to describe harmonies in terms of a pieces nominal key. Moreover, many pieces employ "open" key signatures, particularly those from the in the "post-bop" era of the late 1950s. For example, John Coltrane's "Giant Steps" has a key signature with no accidentals, but is certainly not well-described as being in C major. This issue is present in modal compositions as well: Miles Davis's "So What," for instance, is commonly described as being in D-Dorian, a subtle distinction not captured by key signature alone.

Hence, we considered solely root motion and chord quality in our analysis of chord n-grams, and ignored all chordal extensions. This allowed for a modular analysis of harmonic combinations, regardless of relationship to the tonic. Specifically, we searched for chords of the following types: major, minor, dominant, minor 7th, half-diminished, fully diminished, and augmented. Chord progressions were considered with no reference to their metric position.

The most common 2-chord, 3-chord, and 4-chord progressions across the entire corpus were compiled. The most common two-chord progressions, when viewed in terms of chord type and root motion alone are given below, sorted by the number of occurrences. To aid comprehension, we also include a heuristic description of the type of motion.

8243	mi7 – P4 – dom	"ii – V"
4491	dom – P4 – maj	"V – I"
2562	dom – P4 – min7	"V/ii – ii"
1875	dom – P4 – dom	"V/V – V"
917	mi7 – P4 – mi7	"vi – ii"

Perhaps it is unsurprising to find progressions of the ii-V type toward the top of the list. The results for 3-grams and 4-grams similarly indicate that tonal motion, specifically root motion by a perfect fourth, is quite prevalent within the jazz idiom. The most common three-chord progressions were:

3118	mi7 – P4 – dom – P4 – maj	"ii – V – I"
1534	dom – P4 – mi7 – P4 – dom	"V/ii – ii –V"
1476	mi7 – P4 – dom – P4 – mi7	"iii – V/ii – ii"
642	mi7 – P4 – mi7 – P4 – dom	"vi – V/V – V"
596	dom – P5 – mi7 – P4 – dom	"V – ii – V"

When looking at four-chord progressions, the reliance on what are commonly referred to as "rhythm changes" (I – vi – ii – V) can be seen, as well as a "Satin Doll" progression (ii – V – ii – V):

921	mi7–P4–dom–P4–mi7–P4–dom	"iii–V/ii–ii–V"
730	dom–P4–mi7–P4–dom–P4–maj	"V/ii–ii–V–I"
464	mi7–P4–dom–P5–mi7–P4–dom	"ii–V–ii–V"
418	maj–M6–mi7–P4–mi7–P4–dom	"I–vi–ii–V"
374	mi7–P4–dom–P4–maj–m6–mi7	"ii–V–I–vi"

It is immediately evident that these progressions make overwhelming use of root motion of a P4. Moreover, the progressions have tonal interpretations which are instantly recognizeable. It would seem that the jazz canon we are studying is predominantly a tonal one.

IV. HARMONIC SYNTAX AND HARMONIC SCHEMATA

We wished to make use of the database of jazz chord changes to gain a better empirical understanding of the history of jazz harmony. In doing so, we will make a distinction between two types of harmonic motion: those which constitute short, syntactic motions, and those which constitute a larger schematic framework. The first sort of unit we will describe as being "n-grams" or "sequences" of chords. The latter, we will term "schemata."

Chord sequences such as the 3-gram "mi7 – P4 – dom" are such common events in tonal harmony that they would not typically be considered to be substantial organizing principles governing a work's structure. Instead, we might describe these sorts of short progressions as being part of the syntax of the musical language. This is not to say, that sequences are unimportant or somehow merely incidental to jazz music, nor do we wish to suggest they do not result in higher-level cognitive representations. Indeed, the frequency with which many of these sequences occur makes them tremendously important for novice improvisers to become acquainted with as a first step toward mastery. Improvisers will often rehearse and memorize melodic gestures that accompany specific harmonic progressions. By building a harmonically-based improvisatory vocabulary, players learn to comprehend the modular harmonic progressions of a piece, and can apply their knowledge to many pieces within the idiom.

Simple chord sequences are not the only sort of structure which can be found in jazz, however. Certain discrete sequences of events might be cognitively parsed as instantiations of a larger schematic framework. We will use "schema" to refer specifically to these higher-order abstracted structures which include "slots" which might be filled. (Gjerdingen 1986). Jean Mandler defined a schema as "a mental structure formed on the basis of past experience with objects, scenes, or events, and consisting of a set of (usually unconscious) expectations about what things look like, and/or the order in which they occur." An event schema "includes knowledge about what will happen in a given situation and often the order in which the individual events will take place." (Mandler 1984, p14). When defining schemata, Gjerdingen notes that "we create abstract mental representations of past experiences and then use these abstractions, termed schemata, to evaluate new experiences" (1986, p25).

While one could certainly argue that certain short sequences of chords might very well be describable as schemata, we will use the term to describe slightly larger structures. Notably, our conception of an n-gram is naive to metric placement, and is intended to describe harmonic syntactical patterns, regardless of their position in a measure. By contrast, we will treat schemata as falling within a metric framework, as meter is necessary in understanding the sorts of schematic "slots" which might be filled by different events.

We conducted two studies regarding diachronic changes in jazz harmonic practice, one regarding sequences, and one regarding schemata.

First, we observed that the most common 2-grams, 3-grams and 4-grams in the database represented harmonic motion of a

relatively tonal orientation: root motion by perfect fourth (P4). This gave rise to some hypotheses regarding their distribution over time. We predicted that simple chord sequences which suggest "tonal" harmonic progressions would become increasingly less frequent over the years between 1925 and 1970. This would reflect a transition away from swing and bebop toward modal jazz styles. More specifically, we hypothesized that short chord sequences characteristic of tonal syntax should exhibit a gradual decline during this period. To test this, we measured the rate of occurrence the four most common 2-grams, 3-grams, and 4-grams, all of which included tonal-typical root motion of a rising P4.

Second, we sought evidence for the rise and fall of one particular harmonic schema: the "rhythm changes," named after the opening progression of George Gershwin's "I Got Rhythm" (1930). According to Gjerdingen (1986), a schema's rise in popularity is associated with a period of "progressive association" in which its appearance becomes more and more normative. After its peak, the schema then undergoes a period of deformation, until it is used only sparsely. We hoped to detect evidence of the rhythm changes undergoing just such a rise and fall.

A. A Diachronic Analysis of Sequences

1) Two-Event Tonal Sequences. We hypothesized there would be a downward trend in the usage of tonal 2-grams over time, due to the incorporation of songs representing modal jazz. We plotted the fraction of instances of each of the four most common two-chord sequences in each year between 1925 and 1970, the timespan best represented by our corpus. Figure 6 depicts the prevalence of "ii – V", "V – I", "V/ii – ii", and "V/V – V" types of chord progressions, defined by their quality and root motion alone.

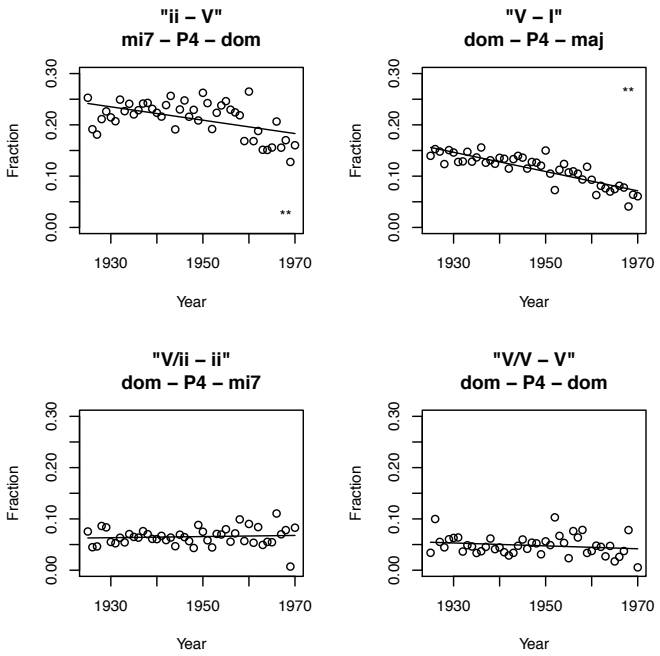

Figure 6: Prevalence over time of four types of 2-grams. 2-grams are defined in terms of root motion and chord quality; Roman numerals are only heuristic descriptions of the type of progression. Consistent with the hypothesis that tonal root motion would become less common over time, "ii – V" and "V – I" progression types exhibit statistically significant downward trends (mi7-P4-dom t_{44} = -3.96, p < .001; dom-P4-maj t_{44} = -11.10, p < .001). No significant trend was detectable for "V/ii – ii" or "V/V – V" types of progression.

As an inferential test, we fit linear models to each 2-gram and conducted two-sided t-tests for statistical significance. The "ii – V" sequences exhibited a statistically significant decline (t_{44} = -3.96, p < .001), as did the "V – I" progressions (t_{44} = -11.10, p <.001). However, we detected no significant downward trend for the "V/ii – ii" or the "V/V – V" 2-grams.

These results are consistent with our hypothesis that tonally-inspired two-chord sequences would become less prevalent over time. It is interesting to note that the prevalence of "ii – V" chord sequences appears to maintain a relatively stable level until the late 1950s, at which point their frequency drops precipitously (Figure 6). This coincides with the introduction of modal jazz styles (for instance, Miles Davis's *Kind of Blue* was released in 1959).

It is possible that the use of the "V – I" variety of chord sequences shows a somewhat different pattern: it would seem that in contrast with the sudden drop associated with ii – V progression frequency, V – I sequences exhibit a more steady decline. This could be interpreted as implying that resolution of harmonic tension in the form of traditional cadences had already become somewhat less common by the mid-1950s. We did not perform a formal statistical test to substantiate this conjecture, however. It would be desirable to formally test this idea using a different database in order to produce converging evidence.

2) Three-Event Tonal Sequences We also conducted a study of three-event harmonic progressions. Like the previous study, it analyzed the fraction of usage over the period ranging from 1925 to 1970. Again, we searched for diachronic trends associated with the four most common 3-grams. However, because the raw frequency of occurrence associated with 3-grams is somewhat lower than two-grams, our study was hampered by a lack of statistical power.

Of the four most common three-grams, only the "ii – V – I" progression type exhibited a decline; other plots had reached the limit of our method's resolution (Figure 7). This decline was found to be statistically significant, and consistent with our hypothesis (t_{44} = -7.395, p <.001). However, no other three-grams exhibited significant trends.

B. A Diachronic Study of the Rhythm Changes Schema

In jazz, the harmonic progression of the opening of Gershwin's "I Got Rhythm" might be the best example of a relatively large-scale harmonic schema. It is often used as a starting point in compositions, and has been one the most typical harmonic gestures of the idiom since its appearance in 1930. A diachronic study of this four-bar progression could reveal the existence of Gjerdingen's arc of typicality in the jazz idiom. Therefore, we targeted the this progression, which can be seen below in one typical form.

I – vi – ii – V – iii – vi – ii – V

This constitutes an eight-chord sequence which provides the foundation for various functionally-equivalent chord substitutions. For instance, one alternative version might be performed as follows:

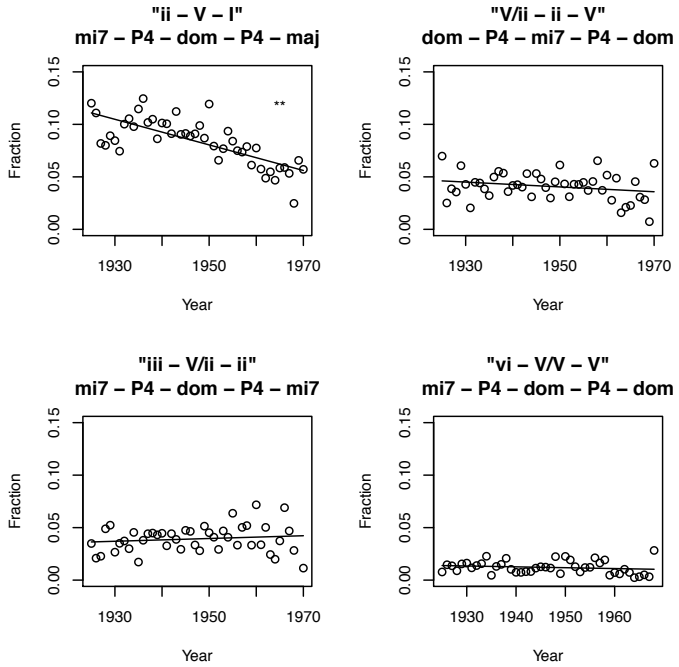

Figure 7: Prevalence over time of four types of 3-grams. 3-grams are defined in terms of root motion and chord quality; Roman numerals are only heuristic descriptions of the type of progression. Consistent with the hypothesis that tonal root motion would become less common over time, "ii – V – I" types exhibit a statistically significant downward trend (mi7-P4-dom-P4-maj t_{44} = -7.395, p < .001). No significant trend was detectable for any other 3-gram.

I – dim7 – V/V – V – iii – V/ii – Vsub/V – V

While on the surface these sequences appear quite different, both in terms of root motion and chord quality, to the enculturated listener of jazz music, both are instantly recognizeable as two instantiations of the same "rhythm changes" schema. Hence, we counted the occurrence of several eight-chord sequences which could serve as an instance of the rhythm changes schema. Because this schema seemed only well-defined for quadruple meter, we restricted this portion of the study to only those pieces in common time.

In order to identify the many different forms of rhythm changes, we began by consulting the work of Järvinen (1995), who provides the following three versions of the first 8 chords in a rhythm changes sequence:

CM7 Am7 | Dm7 G7 | CM7 Am7 | Dm7 G7
CM7 C#o7 | Dm7 D#o7 | Em7 A7 | Dm7 G7
Ab7 Db7 | F#7 B7 | E7 A7 | D7 G7

As can be seen, a great variety of individual chord types might be used to construct the four measures consistent with the rhythm changes schema. In order to search for as many possible instantiations of the progression as possible, we wished to generate an exhaustive list of all possible chord substitutions and reharmonizations which might appear within the idiom. In doing so, we consulted a popular text on jazz reharmonization (Felts, 2002). Specifically, we began with the diatonic version of the rhythm changes, exemplified by two repetitions of the progression "I - vi - ii - V." We subsequently determined which other chords might plausibly appear in each

Table 3: Accepted chord substitutions represented in the key of C major. Note that only the tonic chord was accepted in the first slot. These were generated from the incorporation of (a) secondary dominants, (b) contrapuntal leading tone chords, (c) tritone substitutions, (d) the treatment of the vi chord as an elaboration of the I chord, and (e) introduction of the iii chord in the fifth position.

Position	Options				
Chord 1	Cmaj7				
Chord 2	Cmaj7	Amin7	A7	C#o (Dbo)	D#o (Ebo)
Chord 3	Dmin7	D7	Fmaj	Ab7	
Chord 4	G7	Db7	D#o (Ebo)		
Chord 5	Cmaj7	Emin7			
Chord 6	Cmaj7	Amin7	A7	C#o (Dbo)	D#o (Ebo)
Chord 7	Dmin7	D7	Fmaj	Ab7	
Chord 8	G7	Db7			

of these positions. Specifically, we allowed for the incorporation of (a) secondary dominants, (b) contrapuntal leading tone chords, (c) tritone substitutions, (d) interchange of I and vi, and (e) introduction of the iii chord in the fifth chord position. In our n-gram encoding scheme, these sequences are described in terms of root motion and functional quality only. This scheme is depicted in Table 3.

One could suggest a potential fault with our operational definition. Many of the possible combinations of chords which could be generated by Table 3 would not be acceptable examples of rhythm changes. That is, harmonic syntax might not be well described by a simple combinatorial scheme. Nonetheless, it would seem unlikely that any of the non-syntactic chord progressions would appear with any frequency in the corpus. In fact, of the 12,544 combinations generated by Table 3, only 43 alternatives to the typical "I-vi-ii-V" occurred. We interpreted this to indicate that our measurements were unlikely to have identified inappropriate progressions. Moreover, our operational definition of rhythm changes specifies precise metric organization. This provides some degree of additional assurance that the progressions we identified as instantiating rhythm changes would indeed be heard that way.

By Gjerdingen's (1986) account, one would expect to see the prevalence of a particular schema to show a gradual increase ("progressive association") leading to a time period of peak usage in which individual instances of the schema tend to be quite similar (that is, maximum usage coincides with maximum typicality). Following this, a period of deformation follows. Perhaps the most prototypical version of the chord progression occurs in Gershwin's "I Got Rhythm", composed in 1930. Because our corpus only reliably contains diachronic data between the years of 1925 and 1970, it might be difficult to capture any portion of this hypothesized "progressive association" phase of the schema's lifespan.

Using our four-measure operational definition of rhythm changes, we searched for all matching chord progressions in

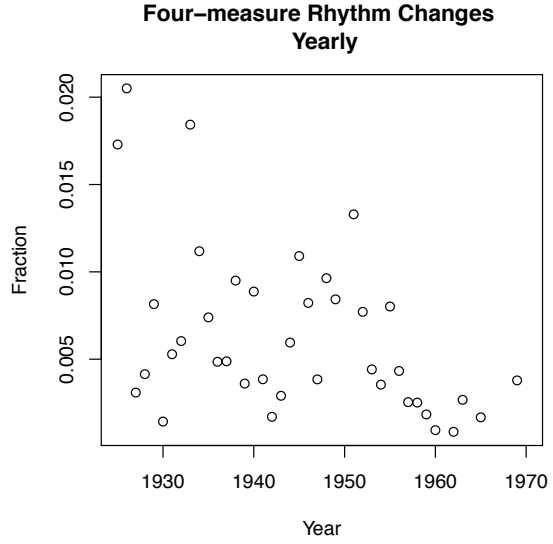

Figure 8: The yearly usage of the "rhythm changes," operationally defined as a four-measure (eight-chord) unit, or its variants, over time as a fraction of overall number of four-measure progressions. Due to a low signal-to-noise ratio, it is difficult to interpret this data set.

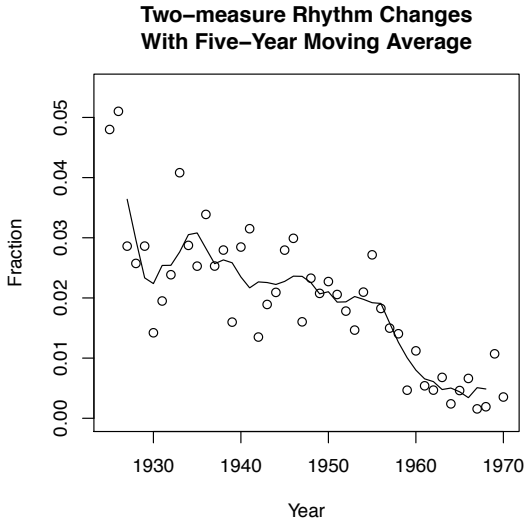

Figure 9: The yearly usage of the "rhythm changes," operationally defined as a two-measure (four-chord) unit, or its variants, as a fraction of overall four-chord progressions used. A five-year moving average is included to assist in visualizing the trend. Within the window studied (1925-1970), no arc-shape could be clearly visualized. In fact, the distribution of rhythm change progressions appears to follow a qualitatively different trajectory, characterized by a sudden drop in prevalence in the late 1950s.

the corpus. These results are given in Figure 8. There appears to be evidence consistent with a decline in the rhythm changes schema's popularity toward the end of the time period. Although there might appear to be the rough contour of the predicted arc shape in the yearly frequency data, one should be careful to note that the signal is quite weak: the fraction of chord changes identified as four-measure rhythm changes is under 1%. Hence, one should exercise extreme caution when interpreting the results of this four-measure operationalization. It would seem that we have insufficient evidence to make strong conclusions regarding the posited arc shape.

In order to increase our analytical power, we decided to reanalyze the dataset using a modified operational definition of rhythm changes. The four-measure operationalization seeks a full four measures of the schema, reflecting how it might appear in the "A" section of a piece. Unfortunately, specifying such a large progression resulted in few matches. Another approach might consider only the first two measures of the rhythm changes: I-vi-ii-V and its various reharmonizations. This operational definition would be able to capture rhythm changes progressions occurring in other contexts than an A section, such as turnarounds or modulatory sections. With this revised definition, our combinatorial scheme yielded 112 possible combinations, of which we identified 25 in the corpus.

The results of our two-measure version of the study succeeded in increasing the detectable signal (Figure 9). With time-series data, a common technique for visualization is to include a moving average line. Here, we calculated a five-year moving average to smooth the data series. While the predicted arc shape was not detected, it appears evident that the schema experienced a decline in popularity.

Specifically, it would appear that the usage of the two-measure (four-chord) rhythm changes schema declines quite rapidly around the advent of modal jazz in the late-1950s. By contrast, it appears to have been used comparatively consistently during the 1930s and 1940s.

Unfortunately, the years preceding 1925 are insufficiently represented in the database. Because of this, we are unable to empirically describe the rise of the rhythm changes schema using these data. One would need to perform a study using a different data source to characterize any "progressive association" which may have occurred.

Nonetheless, the years included in this analysis do allow us to qualitatively characterize the fall in this schema's popularity. There appears to have been a sudden shift in the prevalence of the two-measure rhythm change schema during the late 1950s. This downward trend in the analysis appears to coincide with the sudden drop in the prevalence of the "ii-V" type of two-gram we reported above. It would appear that the results are inconsistent with a gradual "deformation" account of a schema's decline. Instead, the the advent of modal jazz in the late 1950s might have sparked a precipitous fall in the rhythm changes schema's popularity.

VI. CONCLUSION

We employed an electronically-encoded database of jazz chord changes to empirically describe features of jazz harmony, and to test certain hypotheses regarding the use of tonally-inspired syntax and one particular schema: the rhythm changes. We were expecting to find results indicative of a decrease in overtly tonal syntax from 1925 until 1970; results were broadly consistent with this hypothesis. However, the study appeared to be hampered by a lack of statistical power. While there was a decrease in the usage of the most common tonal 2-grams, such as the "ii-V" and the "V-I" types of progression, results concerning the diachronic use of applied dominants were inconclusive.

In formulating an empirical study of the rhythm changes schema, we encountered difficulties formulating a method which would yield sufficient power. The prevalence of two-

measure units representative of rhythm changes was observed to be relatively constant between the mid-1920s and the mid-1950s, at which point the schema appeared to experience a rapid decline in popularity. This observation is somewhat at odds with the arc-shape of prevalence which we predicted. It would be illuminating to study this phenomenon using an independent sample and methodology.

Finally, we must highlight one critically important problem with performing diachronic studies using this corpus. While verifying the integrity of authoritative source materials is a crucial element in rigorous musicological research, the present study instead relies on data extracted from apocryphal sources. As noted earlier, the information contained in this database was not collected systematically, and instead is the product of an *ad hoc* compilation carried out by a group of jazz enthusiasts. These enthusiasts might be hobbyists, amateurs, or professionals.

While we found very good agreement between our corpus and published fake books, it remains the case that these fake books themselves might well have contained several errors. Moreover, while the individual pieces included might themselves accurately reflect jazz practice, they were not sampled in any methodical way. That is, our results cannot be construed to apply to jazz practice as a whole, but only to one particular canon. Nonetheless, we find that there is nonetheless considerable merit in describing this canon systematically, as it seems to have remained the focus of today's jazz culture.

This methodological approach is but one of many possible research perspectives. In our case, we have adjusted our topic of interest to better suit the sources of data which are readily available. More rigorous tests of our conjectures would make use of data collected explicitly for the purpose of testing these ideas. As such, we hope the conclusions of this study will be the subject of further testing, using a variety of methods and sources.

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