The JAZZOMAT project. Issues and methods for the automatic analysis of jazz improvisations

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1 Introduction

Jazz is an outstanding area of popular music. Jazz has even been described as "Americas classical music" and therefore designated by the American congress "as a rare and valuable national American treasure to which we should devote our attention, support, and resources to make certain it is preserved, understood, and promoted" (cit. by Walser, 1999, p. 333). There is a huge and growing number of studies dedicated to the history and social background of jazz, to the lives of various jazz musicians as well as to their music and to musical structures and features of various jazz styles (see Meadows, 1995; Pfleiderer, 2002). Furthermore, for several decades jazz has been on its way to become a real alternative to classical music as instrumental training for young musicians (DeVeaux, 1991) - in the United States of America as well as in various European countries, Australia and Japan.

At the core of the musical competences of jazz musician lies the art of improvisation. From an ethnomusicological point of view, Paul F. Berliner (1994) thoroughly investigated the apprenticeship of young jazz musicians and the transmission of practical knowledge about improvisation within the New York jazz community in the 1980s. Furthermore, the creative processes of improvising and their foundations in embodied cognition have been explored and theorised by psychologists, too (Pressing, 1988; Iyer, 2002; Johnson-Laird, 2002). In contrast to creative processes like composing music or inventing new technical applications, improvising as "creation of music in the course of performance" (Nettl, 1998) is a realtime onstage creative activity without opportunity for correction or editing. Therefore improvising is of particular interest for the psychological scrutiny of creativity.

With the JAZZOMAT project we aim at approaching several issues of jazz improvisation using a database of jazz solos as well as various statistical methods

of music analysis. Therefore, our project is situated at the borderline of jazz research, cognitive psychology of creativity, and statistical music analysis, exploring research issues and methods of all three disciplines. Our intentions are:

- to describe and discriminate different jazz improvisation styles by various features, e.g. with regard to the relations of pitch to metre, tonality and the underlying chords;
- to compare features of jazz improvisation with features in other styles and areas of music;
- to explore the cognitive foundations of improvisation while testing theories about the cognition of creative processes, e.g. by determining recurring melodic and rhythmic patterns and their underlying melodic-rhythmic prototypes;
- the dependence of improvisational material on external parameters like instrument, tempo, key and their interrelationship;
- to evaluate and enhance pedagogical approaches towards jazz improvisation;
- to test and enhance statistical methods of music analysis, e.g. measures of complexity and coherence.

These aims of the JAZZOMAT project will be described in detail in the course of the following sections. The paper is organised into three main parts. At first, we like to go into detail about some issues of jazz analysis as well as research on improvisation in psychology of creativity and cognition, and give a short account of methods of statistical analysis for music databases. In the second part, we want to outline the JAZZOMAT project describing the database of jazz solos we rely on and making some points on the coding of the music data and on statistical routines and algorithms that will be used. Some of them are exemplified in the following part, where we present preliminary results concerning pitch class distribution und (tonical) pitch class transitions in extracts of solos by two jazz saxophonists. Finally, we outline future extensions of our project.

2 Background

Since the 1950s there is a considerable amount of analytical research concerning various jazz styles (see e.g. Meadows, 1995; Pfleiderer, 2002; Knauer, 2005). Since improvisation is regarded as an essential feature of jazz - notably of the modern jazz styles following the swing bigbands of the 1930s - the focus of many of these

studies is not so much composition or arrangement but mainly various styles of improvising. However, the question arises how characteristic features of improvising and improvised music can be reliably described. There are several approaches to jazz analysis, which can divided into work-oriented approaches, relying mainly on the published and authorised records, and process-oriented approaches, focussing on the process of improvising itself (Brownell, 1994). Both approaches are facing methodological problems. On the one hand it is misleading to rely on recorded improvisations alone, because records do not have the status of definitive "works" - in most cases they are not works but performance versions.[1] On the other hand it is not an easy task to describe the processes and strategies of jazz musicians without having the opportunity of thoroughly examining their playing, learning, rehearsing etc. - but with professional jazz musicians this opportunity often simply does not exist. Therefore, jazz researcher Ekkehard Jost argues for a methodology of jazz analysis that starts with records but aims at describing musical principles prevailing an individual style of improvisation. He asks:

"How relevant is an analysis of recorded improvisations made on a certain date and under certain circumstances (the group involved, the improviser's physical and mental disposition, the conditions imposed by the producer, etc.)? This will depend on the extent to which those improvisations can be taken, beyond the immediate musical facts, as indicative of the specific musicians' and groups' creative principles" (Jost, 1974, p. 13). Jost continues that "(. . .) analysing and interpreting the features of a given improvisation demands that the analyst take [sic!] into account everything he has learned from other improvisations by the same musician. The significance of general pronouncements on the stylistic features of an improviser, from whom one has just a single solo at hand, is minimal, while the likelihood of drawing false conclusions is very great" (p. 14).

Jost then argues for a two-step methodology of jazz analysis: At first listen to all available recordings of a musician or a group, and then, choose the typical pieces and analyse them in detail. Many jazz researchers have followed this approach outlined by Jost, among others e.g. analytical investigation of the style of Lester Young (Porter, 1985), Charlie Christian (Finkelman, 1997), Charlie Parker (Owens, 1974), Miles Davis (Kerschbaumer, 1978), John Coltrane (Putschögl, 1993), or Bickl's study of Bebop style improvisation (Bickl, 2000).

It seems evident that the more examples one can rely on analytically the more valid are the results of the analysis. So why listening to all the records and then choosing only one or two typical examples to illustrate the creative principles? Why not relying analytically on as many improvisations as possible? Moreover, an

[1] Of course, some outstanding jazz recordings could be and actually has been appreciated a definite works, e.g. "Kind of Blue" (1959) of the Miles Davis Sextet or "A Love Supreme" (1964) of the John Coltrane Quartet. Keith Jarrett's "Cologne Concerts" (1975) have even been transcribed and published as sheet music.

advantage of a statistical approach with an exploration of as many improvisations as possible is to reveal all analytical procedures, that are too often obscured by a "just listening"-approach of music analysis. So, in our statistical approach to jazz improvisation everything in the analytical process will be made explicit in order to give other researchers the opportunity to repeat the investigations or extend them with more or other data and methods as well.

Of course, there are several musical dimensions to be investigated in improvised melodic lines: first, their tonal and harmonic implications as well as their relation to the original melody and chords they are based on; then, the rhythmic features of the improvised lines including peculiarities like cross rhythms or those micro-rhythmic liberties that contribute to the overall "feel", "swing" or "drive" of a solo (see Benadon, 2006; Busse, 2002; Friberg & Sundström, 2002; Iyer, 2002); furthermore, issues of interaction between soloist and band (see Hodson, 2007), and last but not least the individual instrumental or vocal sound characteristics of a jazz musician. All those features contribute to the overall dramaturgy of a jazz improvisation, often described by metaphors like "telling a story", "making a journey" or "doing a conversation" (see Berliner, 1994), its aesthetic coherence and complexity (respectively simplicity) as well as to the stylistic conciseness and recognisability of a musician or style.

Beside an analysis of the products of improvisations there are several attempts to theorise on the processes and strategies of improvising. In an early appreciation of tenor saxophone player Sonny Rollins, Gunther Schuller (1958) names three different strategies to improvise that are related to different jazz styles: In "paraphrase" improvisation, prevailing in traditional jazz of the 1920s and 1930s, a musician refers closely to the melody of the piece, ornamenting and varying it by several melodic means. Later in the 1930s, 1940s and 1950s it was common to improvise without referring to the melody by inventing new lines suiting to the harmonies of the original composition ("chorus phrase" improvisation). According to Schuller, Rollins often applies a third strategy by varying and "developing" short motives taken from the melody or on the spot ("thematic" or "motivic" improvisation). In addition to these three types of improvising, Barry Kernfeld (1988) names modal improvisation referring not to chords but to scales over longer passages of a piece, or the whole piece, as another important strategy of improvising since the late 1950s. Kernfeld also points at the pivotal importance of patterns, licks or formulas in the course of improvisation. The role of repeated patterns, licks or formulas used during improvisation has become one of the main issues in the study of jazz improvisation and are discussed thoroughly by Smith (1991), Berliner (1994) and Finkelman (1997).

From a psychological point of view, preformed patterns are important tools for an improvising musician. Improvising can be characterised as coping with

multiple tasks under severe time pressure, e.g., inventing interesting melodic lines while following the chords, listening to the other musicians, playing the instrument correctly, keep "swinging" and last but not least monitoring their own playing and paying attention to the audience. In order to cope with all that challenges in realtime, an improviser has to rely upon many routines, e.g., a repertoire of learned patterns (see Pressing, 1988; Berliner, 1994; Johnson-Laird, 2002; Pfleiderer, 2004).

But if improvisers just repeat and recombine patterns, what is the significance of creativity? Philip Johnson-Laird (2002) argues that improvisation is indeed a creative process, because improvisers create new - at least subjectively new - music in the course of playing, within given stylistic constraints in a non-deterministic way. According to Johnson-Laird the creative decision-making process during improvisation could be conceptualised in two extreme ways: At one extreme, the improviser generates many melodic lines casually, adequate ones as well as inadequate ones, and then deliberately chooses a correct and adequate line he executes immediately. At the other extreme, an improviser continually executes adaquate new lines generated at random with the aid of genre rules and constraints he has acquired and internalised. While it is probable that the actual strategy of many musicians lies somewhere in between these two extremes, it would be interesting to explore to which degree an improviser uses cognitive strategies like the two described by Johnson-Laird as well as pre-formed patterns. Therefore, another important question concerning improvisation is, to what degree a musician creates new lines or varies and develops melodic or rhythmic motives - and how much he relies on learned patterns. Also, other questions arise: Which patterns does a particular musician commonly use? Is his pattern repertoire part of his idiosyncratic style or a common knowledge shared by many musicians?

Thomas Owens investigated the repeated use of patterns in the recorded improvisations of the influential bebop-style saxophonist Charlie Parker (Owens, 1974). Owens' analysis relies on many transcriptions of Parkers improvisations and focussed on the role of recognizable patterns used by the saxophonist. Owens identified over 60 patterns that occur many times. Long before automatic devices of statistical analysis were widely available, Owens ground-breaking research is limited by his by-eye-efforts to explore a large number of transcriptions.

Lewis Porter (1985) followed the same approach in his analytical investigation of influential tenor saxophone player Lester Young. In the early 1980s, Porter already used a computer programme to search for 3- and 4-note-patterns in 34 solos of Young. This automated analysis routine forms the starting point for Porters discussion of formulas in three periods (early-, middle- and later-style) of Young's music (see Porter, 1985, pp. 60-65). Moreover, with the help of another computer programme Porter measured the frequency of pitch classes (about 25% of pitch

classes are tonics), of intervals (major second is prevailing), of melodic contours, and of rhythmic patterns in order to characterise and compare Young's three personal style-periods of improvising (see Porter, 1985, pp. 65-81). Unfortunately, Porter gave no specifications concerning the computer programme and only occasionally precise information about the frequencies measured.

Since the 1990s, there is a growing amount of research on musical features using databases of various music styles and statistical approaches implemented on computers (Huron, 2006; Müllensiefen et al., 2008). Several computer tools for automated analysis of symbolical coded music have been developed, e.g. the Humdrum toolkit by David Huron (Huron, 1995) and the Matlab MIDI toolbox by Tuomas Eerola and Petri Toiviainen (Eerola & Toiviainen, 2004). However, most studies focus on classical music or folk and pop songs (Huron, 1996, 2006; Schaffrath, 1995). Jazz improvisation is rarely considered, although it probably will give interesting insight not only in stylistic peculiarities, but also in the cognitive foundation of improvisation. Beside the investigations by jazz researcher Thomas Owens and Lewis Potter discussed above, statistical investigations of jazz improvisation were conducted by Topi Järvinen (1995) and Weisberg (2004).

Järvinen (1995) investigated pitch distribution in relation to the underlying chords as well as to metrical position in several solos of well-known jazz musicians mostly from the bebop and hardbop era. His goals were to compare the tonal hierarchies in bop-style jazz improvisation with tonal hierarchies prevalent in European art music, and to explore how chord progressions and metre affect the choice of notes. He examined 168 eight-bar A-sections of the common "rhythm changes" taken from 18 recordings of Fats Navarro, Charlie Parker, Hank Mobley and others in regard to pitch distribution. His results indicate that, generally speaking, in bop improvisations the same tonal hierarchies can be found as in classical European music. In respect to tonality and underlying chords, musicians sometimes are orientated towards tones "(...) determined by the underlying chord (strong local hierarchy) whereas in other places the hierarchy is determined by the overall tonal orientation of the chord progression (weak local hierarchy)" (Järvinen, 1995). Moreover, the strong points of the metrical structure provides the player with cognitive reference points that help to create coherent improvisations, while syncopations could be seen as events only on the surface, putting additional interest to the improvised melodic lines (Järvinen & Toiviainen, 2000). Besides, Järvinen points at some interesting implications for jazz pedagogy. According to him, many of the teaching practices have been somewhat misleading insofar "(...) they all lack the awareness of the relative importance and large-scale connections of harmony and metre in improvisation" (Järvinen, 1995, p. 435). The statistical approach of Järvinen needs to be expanded to other pieces and musicians - in and beyond the bebop and hardbop tradition. For example, it could be very interesting

to look for tonality in improvisations of post-Coltrane players like Michael Brecker or Steve Coleman.

It is not an easy task to identify automatically licks or formulas in jazz solos. For example, Weisberg (2004) analysed six solos of Charlie Parker, four solos of Lester Young and one additional solo of bass player Jaco Pastorius. All these solos rely on the chords on the jazz standard "Indiana" (Parker based his composition "Donna Lee" on those harmonies). Unfortunately, Weisberg et al. did not take rhythm, metrical position and rests into account but analyzed just chains of intervals regardless how they are placed in the metrical or harmonic framework. Therefore, in our opinion they missed to investigate formulas in the strict sense and the huge amount of 3400 different formulas Weisberg et al. identified in the six Parkers alone is probably somewhat misleading. These results are questionable because two lines of notes with different rhythms or with different rests in between are presumably not recognized as the same pattern by listeners. In addition, while missing to consider phrase boundaries, shorter patterns are classified as distinct formula along those longer formulas that contain the shorter one. Moreover, following Smith (1991) it is questionable to recognize a formula as a one-to-one row of intervals or pitches, while sometimes intervals could be changed, e.g. from a minor third to a major third, while keeping the overall shape of the formula. On the other hand, Smith tends to broaden the concept of formula a bit too wide when he proposes that one could identify formulas by their direction, distance and type of motion, e.g. going up (direction) about an octave (distance) stepwise (type). One could argue, that these kinds of motion classes are not formulas but more like prototypes or schemes of melodic motion. Anyway, the occurrence of that prototypes or schemes in various solos should be analysed, too.

Summarizing the research on jazz improvisation, the following main objectives for a statistical analysis of improvisations arise:

- How can the particular style of an improvising jazz musician be described and different jazz musicians and jazz styles be discriminated? What are the main musical features for style description or discrimination? Several candidates have to be investigated, e.g., melodic patterns, melodic contours, tonality, rhythm, micro rhythm, interaction with context - as well as relations between these features.

- What strategies of improvising are used by musicians in various jazz styles? Are there typical melodic and rhythmic patterns and formulas, prototypes or characteristic rules to create improvised lines? Can styles be discriminated by those patterns or rules? Which percentage of a repertoire of improvisations can be quantitatively characterised as consisting of repeated patterns or formulas, typical melodic motions or contours, new melodic ideas or melodic

cells referring to the original melody or some ideas played before in the course of that particular solo?

- Whether and how such aesthetic qualities like coherence, redundancy, or complexity can be measured?

In the course of the JAZZOMAT project, these issues will be explored with the help of a database and computer-based automatic analysis tools.

3 The Jazzomat project

3.1 The data

We decided to start with investigations of transcribed jazz solos played by single-voiced instruments like trumpet, saxophone or trombone. Since we want to focus on syntactically aspects as conveyed in a symbolic coding first, issues of idiosyncratic sound shaping and articulation are set aside for the time being. Ensemble interaction in jazz improvisation and micro-rhythmic play – both very important issues of jazz too – might be included in the near future since there are some MIDI-transcriptions of ensemble playing commercially available, which provide an easy way of accessing this kind of information.[2]

A SQL database with transcriptions of monophonic jazz solos by various jazz musicians - from Louis Armstrong to Steve Coleman - is currently being built up using standard symbolic codes (EsAC, MIDI) with some extensions necessary for jazz analysis, e.g., phrase boundaries and underlying harmonies. The data can be characterised as follows:

- Due to the importance and for the sake of simplicity of dealing with monophonic instruments, we will rely at the beginning solely on solos of saxophone and trumpet players.

- For reasons of comparison we will include a broad spectrum of styles: from more traditional players like Louis Armstrong to post-bop modernists like Steve Coleman.

- In order to explore the differences between novice's and experts'/masters' improvisations, we will include transcription from jazz students as well.

The sources of data will be manifold:

[2] See the MIDI-files of piano trio performances included in "The jazz pianist", a commercially distributed software by PG Music Inc. Gerard Busse (2002) already used some of these files for his investigation of jazz groove strategies.

- There is a considerable amount of published and commercially available transcriptions.
- Additionally, there are plenty of sources of publicly available transcriptions in the Word Wide Web, sometimes in already digitised form.
- Almost all students of jazz are compiling transcriptions as an important part of the educational process, thus, we plan to draw on such sources, most likely from musicians personally known to us.

Of course, all transcriptions will be cross-checked for mistakes against the original audio recordings.

The database will be structured using an event-based data format where monophonic melodies are resolved in note events consisting of onset, pitch and duration. The events will be stored along with metrical positions and the prevailing harmonic context as provided by the transcriptions. Phrase information will be annotated to the note events as well, since reliable phrase information is crucial for many of our intended analyses. Though, if phrase boundaries are filled in by the data coder, then, we just rely on a single expert assessment. A better solution would be setting phrase boundaries experimentally by a sufficient number of experts. However, such a procedure would have unbearable cost. We plan to mitigate this problem by supplementing the coders segmentations with phrase information of empirically tested segmentation algorithms (e.g., Pearce et al., 2008), which produce gross, but on all accounts musically meaningful segmentation.

Along with the actual solo transcriptions, various metadata will be stored, for instance: title of piece, name and instrument of the soloist, lead sheet of the composition the solo was based upon, tempo and key, if possible, line-up of the band and other musical context information, date, location, producer etc. of the record the transcription was taken from, source of transcription, and a sheet representation of the original transcription. Additionally, for the matter of export and display, other representations of the transcriptions, like CSV, EsAC or MIDI files, will be either stored in the database itself or can be created on-the-fly. The coding itself will be accomplished using an extended version of the EsAC code or by extraction from MIDI files.

3.2 The analysis modules

Since the main objective of the Jazzomat project is in-depth statistical analysis of solo transcriptions, we aim at developing a most general, modular and flexible software framework to enable the broadest range of approaches. Analyses of this kind comprise the following two parts: data transformation (i.e., different, possibly successive abstractions and transformations of the musical surface,

annotations), and statistical algorithms (e.g, descriptive statistics, classification algorithms, modelling).

1. Data transformation: The JAZZOMAT analysis module will provide a wide range of basic data and specific melodic transformations, which might be assembled to transformation chains. These transformations will include, among others (cf. Frieler, 2009 for an exhaustive description):

   - projections (e.g., pitch or rhythm alone),
   - pitch-classes (absolute, tonic or chord-based), semitone intervals, interval classes, Parsons code (interval direction);
   - contour abstractions (linear, polynomial),
   - durations, IOIs, IOI ratios, Metrical Circle Map (Frieler, 2008),
   - cross-products of transformations (e.g., combined metrical position and pitch class),
   - accent transformations (Müllensiefen et al., submitted),
   - (alternative) segmentations.

   With a modular approach of melodic transformation chains (cf. Conklin & Anagnostopoulou, 2001, 2006), several of the issues and problems of analysis procedures (cf. Sec. 2) can be circumvented or even settled. If we consider, for instance, the cognitive nature of melodic patterns, various abstraction levels like intervals, interval classes, combined rhythmic-metric-pitch representations etc. could be investigated all at once and compared with each other, e.g., a comparison of n-gram formulas with or without considering phrase information. Another interesting issue with regard to formulas is the way, how they are embedded in context and the nature of pattern boundaries.

2. Statistical algorithms: In the next stage, the transformed data is subjected to a (possibly chained) set of statistical procedures. The JAZZOMAT analysis module will provide only the most basic statistical methods, mainly of descriptive nature as well as Markov chains and n-gram approaches. Then, more elaborate statistical procedures, e.g. classification algorithms, factor and multidimensional analyses, are accomplished with more effective, specialised statistic sofwtare like SPSS, R or Weka. To this end, an extensive collection of export functions needs to be incorporated in the system supporting a wide range of data formats.

3.3 Example: Markov chains of tonical pitch classes

We will give here only a very tentative example of a possible analysis, which utilises Markov chains of tonical pitch classes (tpc), i.e., pitch classes with respect to the tonic of the piece. To view melodies as Markov chains is one of the most classical approaches in statistical musicology (e.g., Hiller & Isaacson, 1959; Xenakis, 1971; Roads, 1996). Nth-order Markov chains are stochastical time series where the probability of an event depends only on the preceding N events. For many good reasons, which cannot be discussed here, this view is, strictly speaking, never fully appropriate for real music. However, to explore statistical regularities of melodic patterns, this approach is nevertheless useful.

We took two solos already coded in our system, one by hardbop tenor saxophone player Dexter Gordon and one by post-bop alto saxophone player Steve Coleman. The Dexter Gordon piece "Society Red" from the record "Doin'Allright" (Blue Note 1961) is as a medium-slow 4/4 quarter swing based on a traditional 12-bar jazz blues progression (G major), while Steve Coleman's solo is based on a harmonically rearranged 12-bar F minor blues with chord substitutions in bars 5/6 and 9-12 in medium-slow 5/4 time ("Processional" from "Extensions" by Dave Holland Quartet, ECM 1989). We took the first two choruses each with 234 resp. 291 notes and transformed the pitches into tonical pitch classes (tpc), while neglecting rhythmic information. For the two series of tpc's we calculated 0th and 1st order Markov probabilities, i.e., occupation and transition frequencies. Since tonical pitch classes possess a natural cyclic ordering, we chose circle-based diagrams for visualisation purposes, which can be found in Fig. 1. There, the tpc's are ordered counter-clockwise along the circle with tpc 0, which is representing the tonic, being located at 3 o'clock and every subsequent tpc being rotated 30 degrees apart. The 0th order Markov probabilities, i.e., occupation frequencies, are visualised by small grey circles with greyness and size being proportional to the frequency of the tpc. The 1st order Markov probabilities are represented by arrows with thickness being likewise proportional to the frequency of the corresponding tpc transitions. Repetitions are marked by arrows leading from a node to itself. Additionally, in Fig. 2 the zeroth order tpc frequency distributions of the two solos are depicted for easy comparison. From these figures several interesting facts can be read off.

Dexter Gordon is building his solo in a strictly tonal way based on the major scale throughout. The most frequent tpc is that of the tonic, about 16% of the times. Compared to Porter's results for Lester Young's solos of 25% (cf. Sec. 2),

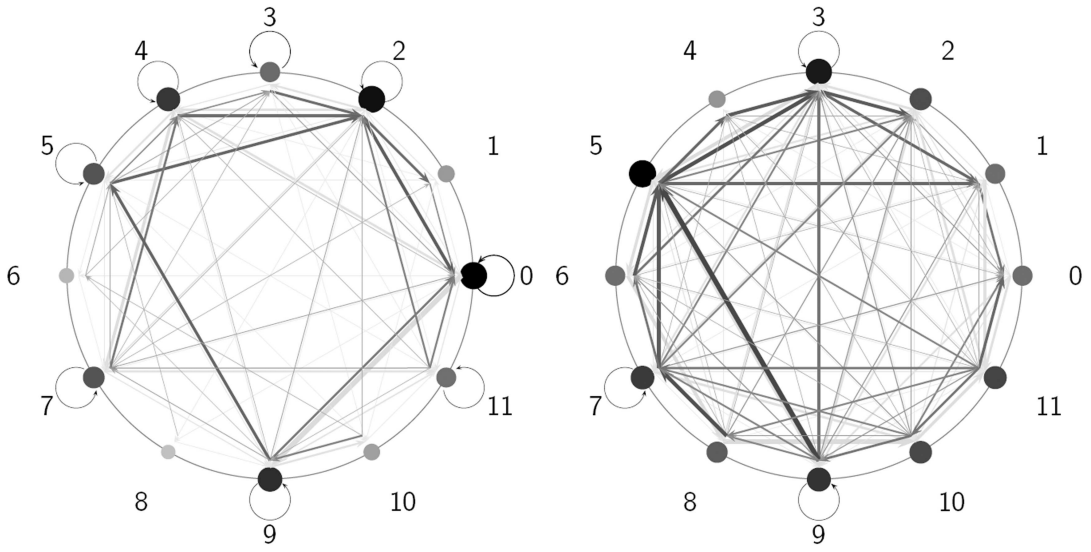

Figure 1: Cyclic representation of Markov chains of tonical pitch classes of the first two choruses of Dexter Gordon's Solo on "Society Red" (left) and the first two choruses of Steve Coleman's solo on "Processsional" (right). The twelve tonical pitch classes are numbered according to their distance to the tonic of the piece. Grey nodes represent occupation frequencies with greyness and size proportional to frequency, the arrows represent transition frequencies with greyness and thickness being likewise proportional to frequency.

the tonic is clearly weakened, which might be a first hint at stylistic differences. As expected in a blues, Gordons frequently uses the minor third (tpc 3), which has about 2/3 of the frequency of the major third (tpc 4). The minor seventh and the tritone or flatted fith, two other so-called "blue notes", however, are muss less commonly used. The flatted fifth (tpc 6) is, in fact, the most rare tpc, whereas the minor seventh (tpc 10) occurs considerably less often than the major seventh (tpc 11), though still much more frequently than in western folk and pop tunes of major tonality (cf. Fig. 3, where the joint Markov probabilities of several hundred European folk tunes and about 50 pop songs are shown). These frequencies of major and minor seventh are in accordance with the concept of the so-called "bebop scale" (see Baker, 1969), which consists of a major scale with an added minor seventh.

Another aspect is the relative strong prominence of the major sixth (tpc 9) in Gordon's solo, which occurs more often than the fifth (tpc 7), being on the third rank only after the tonic and the major second (tpc 2). Moreover, the far most frequent transition is from the tonic to the major sixth (6% of all cases) while the

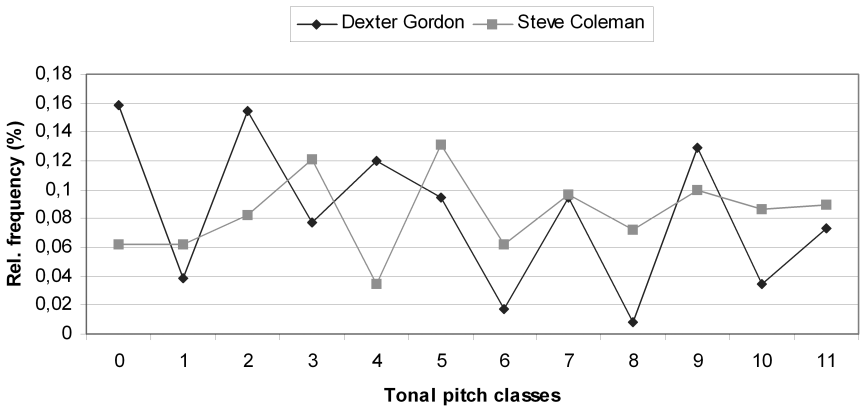

Figure 2: Histogram of relative occupation frequencies of tonical pitch classes of Gordon's and Coleman's solo parts.

next frequent transition from the major second to the tonic is found only in 3.8% of all cases. Whether this slightly surprising fact is a sign for a certain 'bebop way' of playing the blues, a trait of Dexter Gordon's personal style, or just characteristic for this particular solo can, of course, only be decided when more data is available.

For the Coleman solo a quite different picture arises. The chromatic space is nearly completely exhausted, the tonic being now one of the least frequent notes, on the same level as the minor second (tpc 1) and the tritone (tpc 6); only the major third is more rare. The most prevalent tones in this solo section are the fourth (tpc 5) and the minor third (tpc 3), but each with considerably less distance to the following ranks. Major second (tpc 2), fifth (tpc 7), minor and major sixth (tpc 8 and 9) as well as minor and major seventh's (tpc 10 and 11) are nearly equally frequently used. From this tpc distribution alone, the free-floating, chromatic impression of the solo while listening is nicely corroborated.

Looking at the transition probabilities for the Coleman solo some trends can be found. The most frequent transition with 3.1 % of the cases is from the major sixth (tpc 9) to the fourth (tpc 5), the next frequent is from minor sixth to minor seventh (tpc 8 and 10, 2.7%) followed by fourth to minor third and minor sixth to fifth (2.4% each). Moreover, a slight aversion to tone repetitions can be found as compared to Gordon's solo. Another observation is that the space of possible transitions is not uniformly exhausted: 18% of all possible transitions account for 50% and 55% account for 90% of the occurring transitions. (In Gordon's choruses these values are with 11% and 40% slightly lower.)

Comparing both solos, one finds the interesting coincidence that the frequencies of the fifths are nearly identical. However, everything else is quite dissimilar. The most striking fact is the avoidance of the tonic by Steve Coleman as compared

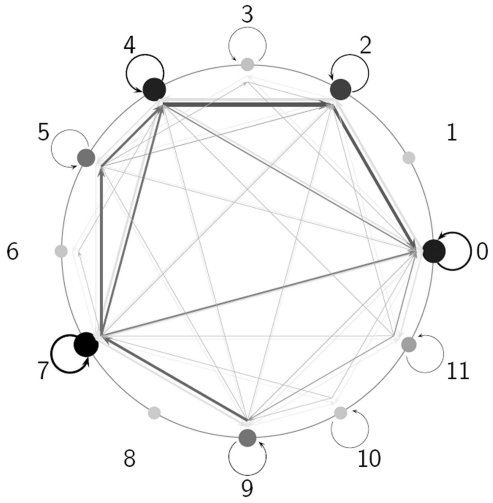

Figure 3: Cyclic representation of joint tonical pitch class Markov chains of several hundred folk songs from Germany, Ireland, Poland, Luxembourg, and of about 50 vocal lines of Top-10 pop songs.

to Gordon's solo, in which the tonic is the most frequent tonical pitch class. As Coleman's solo is based on a rearranged minor blues scheme and Gordon's solo on a major blues, the roles of minor and major thirds are nearly exactly exchanged. However, where Gordon uses the minor third as 'blue note' quite frequently, - not surprisingly - the major third does not take up this role in Coleman's solo. Another interesting similarity can be seen in the strong transitions tpc 9 (sixth) to tpc 5 (fourth) in both solos. Generally, frequency and use of the sixth is more similar in the jazz solos than in the western folk and pop songs, where the sixth is mainly used in close connection with the fifth, as can be seen from the transitions probabilities from and to the sixth in Fig. 3.

Another weak similarity is the treatment of minor seconds and tritones. Though Coleman plays strongly chromatically, these two tonical pitch classes are among the less commonly used, as it is the case in Gordon's solo, too. This is a clear hint that - beyond all chromaticism - Coleman still maintains a concept of minor/major tonality. Furthermore, this is supported by the fact that minor third, fourth and fifth are among the most commonly used tpc's by Coleman.

However, there is a minor caveat to that comparison because the chord progression of "Processional" differs from regular jazz-blues harmonies used by Gordon. This needs to be taken into account to draw final conclusions. One possible approach to do this could be a complementary analysis employing chordal pitch classes, i.e., pitch classes built with respect to the tonic of the accompanying chord, instead of tonical pitch classes.

4 Conclusions and outlook

In this contribution, we presented the concept for JAZZOMAT, an extensive research project, which sets out to explore stylistic, cognitive, and aesthetical aspects of jazz improvisation. Since the implementation of this project is currently at its very beginnings, we could only present some exemplary analyses, which - nevertheless - should have given an impression of the potential power of a statistical approach to jazz improvisation, which, by so far, has been only sporadically employed in research on jazz improvisation. Besides the core concepts outlined above, some futher points and ideas for future extensions should be mentioned:

1. **Publishing the database**. Since a database of jazz solo improvisations would be of high value for the whole field of jazz research, and possibly as well for the Music Information Retrieval community, we wish to make the database and the analysis tools publicly available. This could be either done as a standalone package or as a web service. Moreover, in order to achieve a permanently growing database, we plan to devise suitable user interfaces which will allow all interested contributors to add transcriptions on their own.

2. **Empirical validation of results for incremental improvement of analysis tools**. In order to constantly assess the validity of our analyses, particularly those employing cognitive-modelling algorithms like phrase segmentation, accent perception, metre induction etc., we plan on conducting a series of listening experiments as an integral part of the project. This would be optimally done in a incremental cycle of analysis, validation, modification, and re-analysis. We consider several experimental approaches, for example:

   - distance or similarity judgements of various personal styles and/or jazz genres;
   - evaluation of coherence, complexity, and other aesthetical aspects;
   - comparison of real improvisations and artificially generated solos.

3. **Statistical modelling of jazz improvisation.** So far, concerning research on cognitive dimensions of improvisation (cf. also Pressing, 1988) there have been only few attempts to model jazz improvisation following an analysis-by-synthesis approach. For instance, Petri Toiviainen (1995) trained a neuronal network with several solos of jazz trumpeter Clifford Brown in order to generate jazz improvisations which utilise the target tone technique. A model for jazz improvisation by Philip N. Johnson-Laird (1991, 2002) never got

beyond the stage of preliminary thoughts, although he devised a programme that was able to generate walking bass-lines over a given chord progression. However, cognitive research on improvisation does not, or at least only indirectly, aim at analytically describing already improvised music of various jazz musicians in various jazz styles. Notwithstanding, an analysis-by-synthesis approach is appealing for generating cognitive valid analyses in so far as analysis results can be fed into synthesis algorithms, which in turn can be quite easily validated empirically.

In our view, the JAZZOMAT project promises to reveal important facts about improvised jazz solos and about jazz in general, which will help to significantly improve our knowledge about the creative processes and stylistic constraints involved, that in turn might have several implications for jazz pedagogy.

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