DIVINE RATIONALITY: COMPUTATIONAL TRANSCRIPTION OF CHANTS AND PARAMETRIC STRUCTURING FOR COMPOSITIONS FOR VOICES AND INSTRUMENTS

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ABSTRACT

Our ongoing research into computational ethnomusicology, undertaken first in the project *Computational Ethnomusicology* and continuing in the projects *Tunes and Tales* and *Sounding Philosophy,* has allowed for a better understanding of the roles of scales, melodic contour and tuning in Jewish, Islamic and Christian chant traditions. While this research has also given way to new modes of notating chant cultures via computational means, it has also had a profound effect on the creation of what Dániel Péter Biró has termed historicized composition, a way of creating compositions that respond to, in this case, the historical development of chant traditions. To this end, the methodologies used for computational transcription of these chant traditions have been incorporated in compositional sketches and in innovative notational frameworks for new vocal music compositions. The following paper explores the methodology of this research, its technical properties and resulting compositional output, presenting examples from vocal and instrumental compositions completed between 2014 and 2022. Finally, we propose future work in these interdisciplinary research areas.

INTRODUCTION

Since 2011 we have been working collaboratively to analyze various chant traditions with computational means. This research was an outgrowth from Dániel Péter Biró's PhD research into Hungarian, Jewish and Christian chant traditions [1] as well as Peter van Kranenburg's PhD research into computational analysis of Dutch folksongs [2]. The initial fieldwork in the Netherlands, done as part of the *Tunes and Tales* research project involved recording members of Jewish and Islamic communities in the country. Each recording was then converted to a sequence of frequency values using the YIN pitch extraction algorithm [3]. The analysis of scales, melodic contours and tuning of these examples inspired a new kind of compositional methodology, allowing for the structuring of musical parameters such as pitch, timbre, tuning and instrumentation. Translating the various semiotic and phonetical structures found within the studied chant traditions, new notational frameworks were created.

1. COMPUTATIONAL ANALYSIS OF CHANT REPERTOIRES

The use of models deriving from various chant traditions has a long history. In the 20th century, the work of Olivier Messiaen long existed as a model of compositional integration of chant from various religious and world traditions. While Jewish and Islamic recitation traditions have been integrated within historical, twentieth and twenty-first century compositions by, among others, Josef Tal, Tristan Murail, Kaija Saariaho, Jonathan Harvey, Hans Zender, Samir Odeh-Tamimi, Katia Makdissi-Warren and José Maria Sanchez Verd, the integration of phonetic and semiotic structures found in these traditions has often been a secondary objective. The work of Béla Bartók (1881–1945) still exists as paramount in terms of being a model for connecting ethnomusicological research and musical creation.

In terms of integrating elements from Jewish, Islamic Christian chant traditions, the specific nature and functionality of each tradition had to be considered.

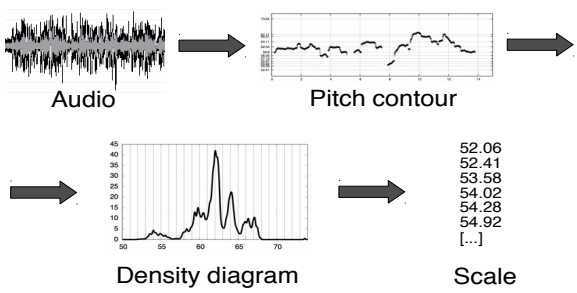
The accents for Torah cantillation are called *ta'amei hamikra,* which translates into "the taste" or "the meaning" of "the reading." These melodic signs, developed between the 7th and 9th centuries by the Masorete rabbis, were concurrently inscribed along with the vowels of the Hebrew letters in order to ensure accuracy in future Torah reading, thereby altering the previous mode of oral transmission. Within its ritual function, the Torah is not only sung but "read," as both syntactical and semiotic meaning is determined by the melody, which also functions to enable correct pronunciation. The ritual of "reading" exists to interpret the sacred Hebrew text, the textual sanctification enabled through the transmission and remembrance of a given Torah trope melody [1].

The word 'Qur'an' refers to the root q-r, and can be understood as "the recited."[4, p. 27]. [1] The performance framework for Qur'an recitation is governed by the rules of recitation. Here the hierarchy of spoken syntax, expression and pronunciation play a major role in determining the rules of *Tajwīd* and *tartīl* [5, p. 21].[2] The resulting melodic phrases, performed as "recitation" are determined by both religious and larger musical cultural contexts. In the context of "correct" Qur'an recitation contexts, improvisation and repetition exist in conjunction. The first Christian plainchant neumes appeared in the 9th century, evolving from a logogenic culture that was based on textual memorization, the memorized singing of chants being central to the preservation of a tradition that developed over centuries [6, p. 445].[3] Like with the Jewish *te'amim*, text existed as a precondition for the development of melody, the words of the chants being notated a century before the first neumes. Christian plainchant notation became a device that not only functioned to reconstruct melody, an aide-mémoire, but also to musically interpret textual pronunciation, syntax and meaning [1].

Within the framework of our research, we have recorded and analyzed examples of Qur'an recitation and Torah trope in various countries including the Netherlands, Tunisia, Israel, Germany and elsewhere [7], [8]. The recordings were put into a database and studied according to a variety of criteria including tuning, melodic contour, melodic range and scale employment (Example 1).[4] This research was also accompanied by interviews with the reciters about their background, including family history, their religious education and general questions about their ritual practice. This ethnographic knowledge informed the analysis methods and the integration and translation of elements from these traditions within the given compositions.

2. HISTORICIZED COMPOSITION INFORMED BY COMPUTATIONAL ANALYSIS OF CHANT

Over the last 30 years, Dániel Péter Biró has composed a series of works informed by Hungarian, Jewish, Christian and Islamic chant traditions. Since 2009, this compositional work has been increasingly informed by computational analysis of these chant traditions first undertaken in the context of the project *Computational Ethnomusicology* and carried forward in the projects *Tunes and Tales* and *Sounding Philosophy* [7], [8], [9], [10].



Example 1. Computational analysis methods allow one to analyze the scales, tuning and melodic contours of given recitation performance. Pitch is represented as MIDI note numbers, with the deviation in cents as decimals.

Within these projects, we recorded a given reciter reciting the same recitation over a series of years to test how memory plays a role in terms of melodic stability. Computational analysis of the resulting audio recordings was undertaken to find the most prevalent pitches within a given recitation.

In this research, we have set out to compare the performance practice of Torah trope recitation as it is done in a variety of cultural contexts. The computational method that we developed delineates the main pitches of a given scale from secondary "ornamental" pitches. By doing so, we presented a hierarchy of scale degrees, thereby showing how surrounding "ornamental" pitches structurally interact with the main "skeletal" notes of the scale within and across Torah recitation traditions.

In terms of studying *Qur'an* recitation, we were able to investigate the practice of *maqamat* (a set of pitches for melodic performance found in Qur'an recitation) in terms of phrase analysis to demonstrate the most prevalent pitches within a given performance in terms of foreground, middle-ground and background frequency analysis. While these pitches relate roughly to *maqamat* traditions of instrumental music, the melodic entities within Qur'an recitation do not adhere strictly to these [11, p. 9].[5]

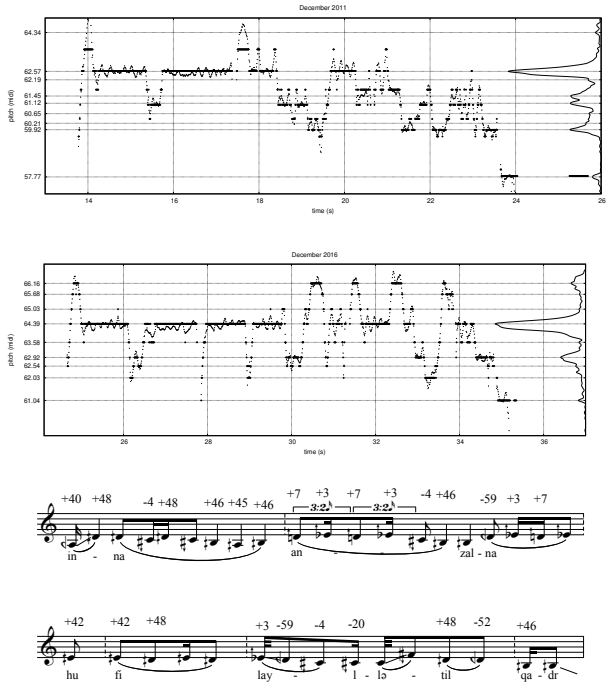
[1] "Like the Hebrew *miqra'* the primary name 'Qur'an' derives from the root q-r, i.e., 'reading': the visual implication of text is not implied with this root. Rather the concepts 'pronounce, calling, reciting' are expressed with the word, so that an adequate translation of Qur'an (Qur'ān) could be 'the recited'" (Translation from German by Dániel Péter Biró).

[2] "*Tajwīd* [is] the system of rules regulating the correct oral rendition of the Qur'an. The importance of *Tajwīd* to any study of the Qur'an cannot be overestimated: *Tajwīd,* preserves the nature of a revelation whose meaning is expressed as much as by its sound as by it content and expression, and guards it from distortion by a comprehensive set of regulations which govern many of the parameters of the sound production, such as duration of syllable, vocal timbre and pronunciation."

[3] "Through the studies of Solange Corbin it has become evident that the neumes are of Carolingians origin. They were developed in France in the ninth century [...] Perhaps neumes were developed and used at first for theoretical demonstrations, and only occasionally employed to notate a particular melody or to give musical explanations here or there in a particular manuscript."

[4] Each recording has been segmented in terms of syntactical units (phrases) and analysis has also been based on audio segments corresponding to individual words of a given Qur'an *sura* or Torah *parasha.* Each recording has been converted to a sequence of frequency values using the YIN pitch extraction algorithm [3] by estimating the fundamental frequency in a series of overlapping time-windows of 40ms, with a hopsize of 10ms. The frequency sequences have been converted to sequences of real-valued MIDI pitches with a precision of approximately 1 cent (which is 1/100 of an equally tempered semitone, corresponding to a frequency difference of about 0.06%). A MIDI-value of 60 corresponds with the c', 61 with equal tempered c#', 62 with d', and so on. A value of e.g., 60.23 would correspond to a pitch that is 23 cents higher than c'.

[5] "Although Qur'anic recitation does not adhere strictly to the modal (maqam) practice of the secular music, and although members of the culture maintain a notion of rigid boundaries separating Qur'anic chant from all the other sound arts, Qur'anic recitation does conform to many of the theoretical aspects of Arabian music. It employs many of the interval combinations (trichordal, tetrachordalor, pentachordal) that identify apjns (s. jins) on which the secular music is based – e.g., bayyatl, ijaz,



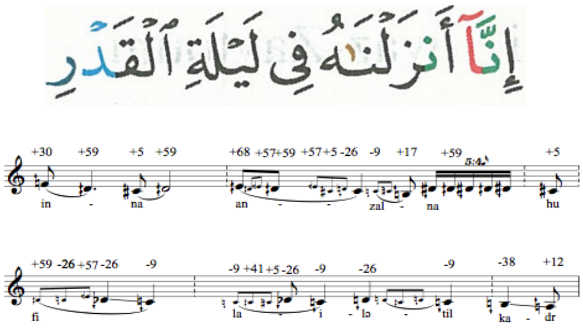
Example 2. Pitch analysis of recordings of recitation Sura *Al Qadr* performed in 2011 (top) and 2016 (bottom) with accompanying transcription as performed by a member of the Al Hikma Mosque in the Hague, Netherlands.

In our analysis, we have often compared renderings of the same reading of the same passage, done several years apart by a given reciter. Comparing the details of these readings reveals patterns of stability and – to a lesser extent – variation over time. Example 2 shows the pitch analysis of two readings of one ayah of Surah *Al-Qadr* as recited by the same reciter in the Netherlands, more than four years apart. We observe that the contour of the phrase shows stability, while the actual pitches, and consequently the scales, show different characteristics.

Such computational analysis provided scale tones for the transcription of these recitations with exact cent values, as shown in Example 3. Such methods of computational transcription, allowed for the basis of scales employed in the works composed in this period.

3. COMPUTATIONAL TRANSCRIPTION OF CHANT AND COMPOSITIONAL TRANSLATION

In this project, the computational analysis allowed for a new kind of compositional sketch, which became the basis for ensuing compositional procedures to structure sonority and form. Simultaneously, such computational models

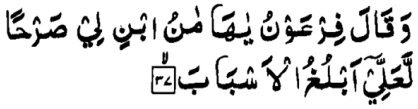


Example 3. Transcription of Sura *Al-Qadr:* Recited in 2011 by a member of the Indonesian Muslim Community in The Hague.

needed to be interpreted in terms of their cultural context and accompanying recitation praxis. This required additional types of notation that would take the practice of vocal music beyond notational frameworks where the parameters of pitch and rhythm remain primary.

The composition *Al Ken Kara (That Is Why It Was Called)* (2013-2014) dealt with the Hebrew Bible text of the Tower of Babel (Genesis 11:1–9) [9]. The piece not only attempted to create a musical analogy to the breakdown of a unified, comprehensible language but also to show how various religious traditions created diverging types of phonetic, syntactical and notational contexts. Employing thirty-six languages, the composition integrates melodies from Ashkenazi Torah trope, Tunisian Qur'an recitation and plainchant. Ahead of the completion of the composition, the composer was able to research Jewish and Islamic chant practices in Tunisia and these became integrated into the work.

Toward the end of the composition, fragments of the Qur'an sura *Ghafir,* which in the composition is recited by the tenor, are incorporated into the now established polyphonic framework of the composition. The fragmented citations of Qur'an recitation, derived from Sura *Ghafir,* which tells of a tower that is, reminiscent to that of Babel:

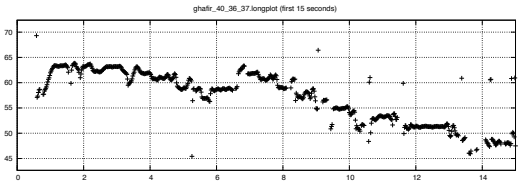


Pharaoh said: "O Haman! Build me a lofty palace, that I may attain the ways and means [12, p. 738].[6]

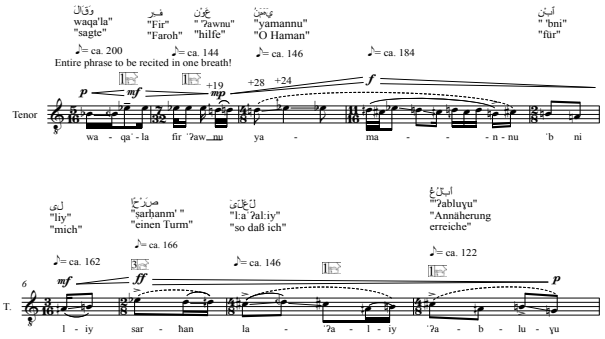
Ahead of writing the composition, a Tunisian rendition of sura *Ghafir* was analyzed via computational means. Example 4 shows the computational contour transcription of

kurd, rast, nahawand, saba, slkah, etc. It similarly evidences a predominance of serial treatment of individual ajnas rather than utilization of the whole modal scale in a single phrase. Cantillation of the scripture is punctuated, like secular improvisations, by returns to the tone (qarar) of resolution in the jins. It is marked by transpositions and modulations internal or external to the phrase, which are also characteristic of the secular genres. Some reciters are knowledgeable about maqam practice and the theory of music. Others have no formal exposure to music theory and only conform to its rules in such measure as their ears and listening experience have trained them."

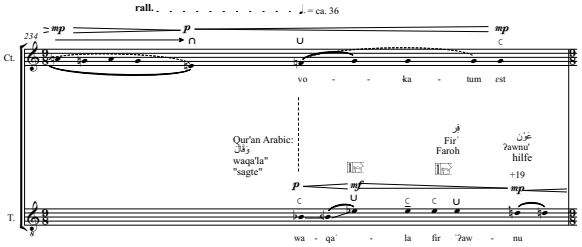
[6] "Muslim exegesis recognizes the presence of Haman alongside Pharaoh in building the tower of Babel in Q. 28:36/42 and Q. 40:36-7." Also see [13, p. 40].



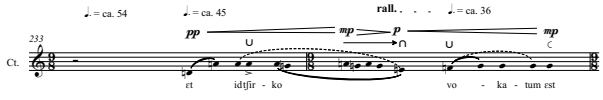
Example 4. Contour analysis of sura *Ghafir.*



Example 5. Transcription of Qur'an sura *Ghafir* as recited in Tunisia.



Example 6: Presentation of section of *Al Ken Kara (That Is Why It Was Called)* incorporating text and melody from Qur'an sura *Ghafir* as recited in Tunisia with scale pitches derived from computational analysis, the rhythmic profile interacting with the line of the countertenor, which is derived from a 14th century Czech plainchant [14].



Example 7. Agogic notation used in *Al Ken Kara (That Is Why It Was Called)* in conjunction with plainchant melody sung by countertenor.

the first 15 seconds. This analysis allowed for a transcription based on 10 scale tones, displayed in Example 5.

Within this composition for seven voices, this sura is cited, its scale becoming the basis for the melodic line of the tenor. Here *tajwīd* and *tartīl,* the rules governing the correct oral rendition of the Qur'an, are integrated into the notation [9], [5]. The signs above the notes indicate temporal elongation, constriction, acceleration and de-acceleration as well as mouth placement for the correct Arabic pronunciation. These elongations were based on the computational analysis, which set out to define how processes of elongation (Arabic: *madd)* could be transcribed within a cross-cultural music composition [7, p. 75].[7]

While the pitches for this transcription were derived from the computational analysis, a suitable notation needed to be found for the complex rules of pronunciation and elongation *(madd)* as found in Qur'an recitation [11, p. 10][8], [7], [9]. Here the signs above the notes served to indicate where a tone was shorter ⊂ or longer ∪ which allowed for a certain flexibility in terms of interpreting the temporal structures present in our analysis of the sura *Ghafir* recitation. This notation to indicate agogic changes is also employed for the transcription of the Czech plainchant based on the text of the tower of Babel "Et idcirco vocatum est Babel nomen loci illius quia ibi divisum est labium universae terrae" [15, p. 16].[9]

4. VOCAL NOTATION INFORMED BY QUR'AN RECITATION

Within these compositions, *tajwīd*[10] and *tartīl*,[11] the rules and practice governing the correct oral rendition of the

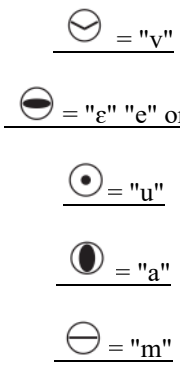
[7] "In our computational analysis we have looked for salient pitches within a recording, within each phrase and within words with syllable elongations *(madd).* Comparing the pitches employed in sections of textual elongation with those employed throughout a given recitation, we have found that the rules of *tajwīd* display a profound influence on creating and stabilizing salient pitches. In addition, through comparative analysis of the same *sura* recited by the same person, we are able to show scale relationships and recurring patterns of final selections of tones within these sections of elongation."

[8] "Durations of tones and rhythmic motifs are strongly affected by the rules of pronunciation set down in the manuals on *tajwid.* Those rules prescribe determined durational relationships between the short vowels or barakat (the fathah, dammah, and kasrah) and the long vowels (i.e., the letters alif, waw and Tajwld also determines the extension or madd of the long vowels according to their place in the word, their combination with certain other letters of the Arabic alphabet, and their use with unvowelled consonants (i.e., with sukon) or doubled consonants (tashdld. 7) These rules insure that the difference between the short and long syllables does not exceed the ratio of 1 to 6 (e.g., the difference between a 16th note and a dotted quarter). Often the actual differences are much less. Many of the prohibited practices regarding Qur'anic chant, which have been repeated and reemphasized in each successive century of Islamic history, have been restrictions against vocal practices that exaggerated durational contrast. Among these condemned practices are the exaggerated lengthening of short vowels (tshba'al harakat), the lengthening of the long vowels (ziyadahal, madd), omission of short vowels (taqtl'al buro1), and the improper addition of short vowels (tahrikal harf al sakin) (al Sa'ld 1967:347)."

[9] The English translation reads: "Thus the LORD scattered them from there over the face of the whole earth; and they stopped building the city."

[10] "*Tajwīd* [is] the system of rules regulating the correct oral rendition of the Qur'an. The importance of *Tajwīd* to any study of the Qur'an cannot be overestimated: *Tajwīd* preserves the nature of a revelation whose meaning is expressed as much as by its sound as by its content and expression and guards it from distortion by a comprehensive set of regulations which govern many of the parameters of the sound production, such as duration of syllable, vocal timbre and pronunciation," [5, p. 16].

[11] "*Tartīl,* in the science of the Qur'ān, an incantatory mode of recitation." See "tartīl," in [16].



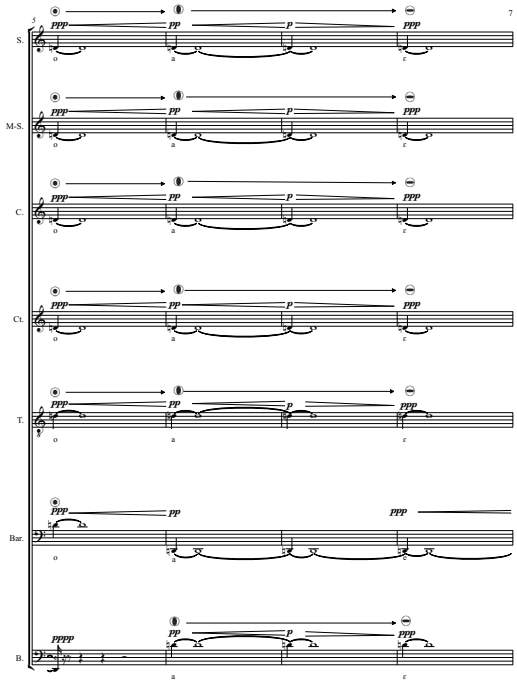
Example 8. Mouth and lips positions (in relation to consonants or vowels).

Example 9. Tongue positions in relation to mode of production and pronunciation

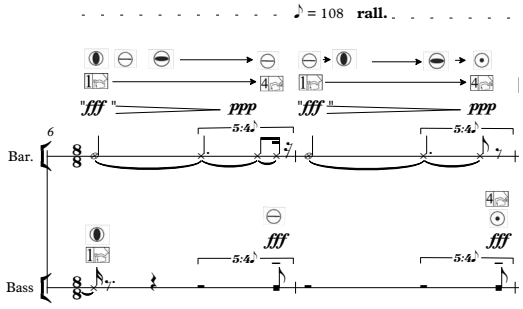
Qur'an, informed the creation of the notation, which indicates temporal elongation, constriction, acceleration and de-acceleration as well as mouth placement for correct Arabic pronunciation.

To emulate such techniques, a notational framework was created to allow the singers to correctly pronounce the Arabic text. Simultaneously, the notational framework provided the basis for new, yet "unheard" vocal sonorities. To this extent, two notational frameworks were employed for mouth and lip positions as well as tongue positions [17][12] (Examples 7 and 8).

While these notational frameworks were often used to emphasize pronunciation, they also allowed for totally "abstract" musical frameworks, far away from the world of sacred texts devoid of any concrete language. This was the case at the beginning of the composition *Al Ken Kara (The is Why It Was Called)*, where a kind of "pre-language" is created before the first enunciation of the Biblical text. Here, the notation of mouth positions was employed to ensure a gradual transition between vowel sounds and resulting changes in overtone spectra in many of the works.



Example 10. Notation of mouth positions for overtone singing at on the single tone of D3 at beginning of composition based on the text of the *Tower of Babel.*



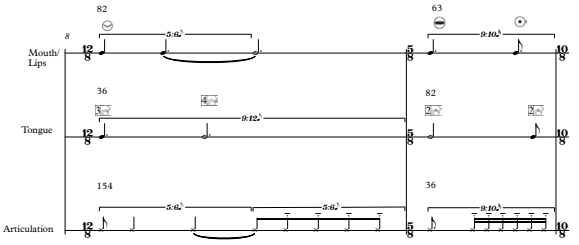
Example 11. Mouth positions combined with vocal techniques (whispering, inhaled whispering, throat tremolo) in mm. 6–7 in movement *Deus Sive Natura* in *Scholium Secundum* after Baruch Spinoza.

5. THE MUSIC OF NATURE: CONSTRUCTING SONOROUS STRUCTURE WITH GEMATRIA

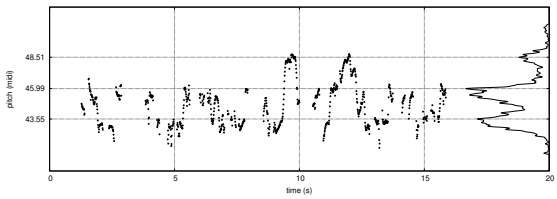
In the composition *Scholium Secundum* (2017–2022), notation was developed to create a sonorous framework that exists as an analogy to the concept of nature and the divine, as conceived by philosopher Baruch Spinoza (1632–1677) [10], [18, p. 296].[13] In the eighth movement of the composition, entitled *Deus Sive Natura,* a notational framework

[12] Such a notation was based on Aaron Cassidy's *A Painter of Figures in Rooms (2012).*

[13] In the fifth chapter of his *Ethics*, "On Human Freedom," Spinoza writes "For the eternal and infinite Being, which we call God or Nature, acts by the same necessity as that whereby it exists. For we have shown, that by the same necessity of its nature, whereby it exists, it likewise works (I. xvi.). The reason or cause why God or Nature exists, and the reason why he acts, are one and the same. Therefore, as he does not exist for the sake of an end, so neither does he act for the sake of an end; of his existence and of his action there is neither origin nor end."



Example 12. *Scholium Secundum* (2017–2022) Canon formed by combination of mouth positions tongue placement and articulation in movement *Deus Sive Natura,* after Baruch Spinoza.



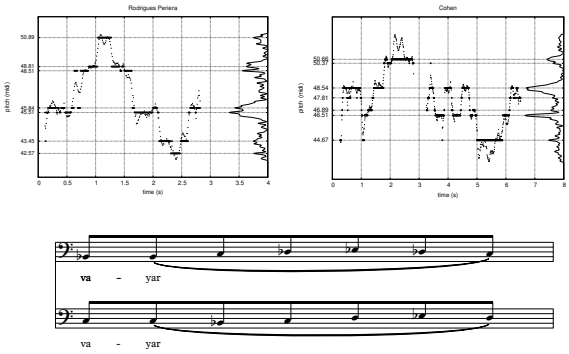
Example 13. Computational contour analysis of Torah recitation as practiced at the Portuguese Synagogue in Amsterdam.

was created to structure mouth and tongue positions, as various methods of sound production (whispering, inhaled, tremolo and vocal-fry techniques) were employed to produce an abstract "music of nature" following Spinoza's ideas.

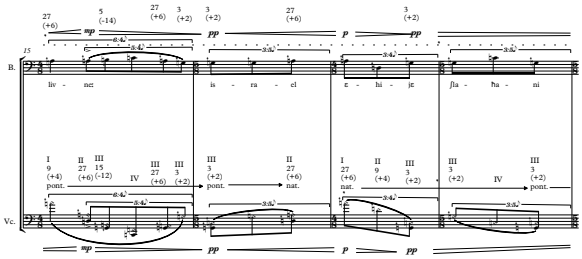
In this movement, the initial sketch was based on Gematria values of Spinoza's text [10], [19].[14] Here a canon, determined by the gematria values, initially forms the various durations of the three types of sound production (mouth/ lips, tongue and articulation).

6. HISTORICIZED COMPOSITION: MELODIC CONTOURS RE-MEMBERED

The pitch material for the twelve movements of this composition derives from melodies from the Portuguese synagogue in Amsterdam, the very synagogue from which Spinoza was excommunicated [20]. The computational analysis of the recorded recitation, as practiced at the Portuguese Synagogue in Amsterdam, presents not only the exact pitches but also the large-scale melodic contour. This melodic contour became integrated within an overtone-based harmonic framework of the composition.



Example 14. Analysis of melodic contour as practiced by two reciters associated with the Portuguese Synagogue in Amsterdam.



Example 15. Recomposed Torah melody in seventh movement of *Scholium Secundum* based on the computational contour analysis of Torah recitation as practiced at the Portuguese Synagogue in Amsterdam.

Recording various members of the Portuguese Synagogue in Amsterdam, we were able to compare differences between reciters. We were able to analyze how the Torah recitation melodies transformed over the course of the twentieth and twenty-first centuries. As illustrated in Example 14, a recitation practice from one practitioner is compared to another. We can thus perceive that, while both reciters employ a similar modal scale for their recitation, which is the normative framework for Torah recitation, the melodic gestures vary.

This contour analysis of this Torah melody formed the basis of the sixth and seventh movements of the composition. Here the tenor, which recites the melody, is accompanied by the cello, its varying string placement indications (tasto, naturale, ponticello, molto ponticello) providing a timbral analogy to vowels of the Hebrew text (u = tasto, a = nat. and i = pont) [10].

[14] Gematria was employed in terms of creating musical structures from both the Hebrew and Latin texts (using *Latin Qabalah Simplex).* The Latin gematria is based on premises of Hebrew Gematria: "The substitution of numbers for letters of the Hebrew alphabet, a favorite method of exegesis used by medieval Cabbalists to derive mystical insights into sacred writings or obtain new interpretations of the texts. Some condemned its use as mere toying with numbers, but others considered it a useful tool, especially when difficult or ambiguous texts otherwise failed to yield satisfactory analysis. Genesis 28:12, for example, relates that in a dream Jacob saw a ladder (Hebrew *sullam)* stretching from earth to heaven. Since the numerical value of the word *sullam* is 130 (60 + 30 + 40) – the same numerical value of Sinai (60 + 10 + 50 + 10) – exegetes concluded that the Law revealed to Moses on Mount Sinai is man's means of reaching heaven. Of the 22 letters in the Hebrew alphabet, the first ten are given number values consecutively from one to ten, the next eight from 20 to 90 in intervals of ten, while the final four letters equal 100, 200, 300, and 400, respectively. More complicated methods have been used, such as employing the squares of numbers or making a letter equivalent to its basic value plus all numbers preceding it."

7. CONCLUSIONS

In our analyses of Jewish, Islamic and Christian chant repertoires, we have set out to discover how salient pitch structures, contours and scale structures are determined and how these relate to the performance practice and larger cultural frameworks of these traditions. Simultaneously, the resulting computational analysis presents transcriptions of the chant repertoires. Combining computational analysis of resultant pitch structures determined by specific rules of Qur'an recitation and Torah Trope, we better understand how the rules for correct enunciation help to form and interact with given tonal hierarchies found within performances of both traditions. Simultaneously, we were able to create compositional sketches based on this material, allowing for musical structures wherein pronunciation, vocal timbre and sonority become main foreground parameters, allowing for new compositional strategies and frameworks for musical material development. Recent advances in deep learning and audio processing enable a less labor-intensive procedure to analyze and compare different chant recordings. In the next stage, we will employ automatic alignment of text and audio to bypass the need for manual annotation of the word and syllable boundaries in the audio files. Thus, we will be able to make comparisons on a larger scale. This will allow for a better understanding of these chant traditions, also allowing for new perspectives for recitation transcription and vocal composition.

Acknowledgments

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8. REFERENCES

[1] D. P. Biró, *Reading The Song: On the Development of Musical Syntax, Notation and Compositional Autonomy: A Comparative Study of Hungarian Siratók, Hebrew Bible Cantillation and Ninth Century Plainchant from St. Gallen.* Princeton University, 2004.

[2] P. van Kranenburg. *A Computational Approach to Content-Based Retrieval of Folk Song Melodies.* Ph.D. thesis. Utrecht: Utrecht University, 2010.

[3] A. de Cheveigné and H. Kawahara, "YIN, a fundamental frequency estimator for speech and music," *The Journal of the Acoustical Society of America*, vol. 111, no. 4, pp. 1917–1930, 2002. https://doi.org/10.1121/1.1458024

[4] H. Zimmermann, *Tora und Shira: Untersuchungen zur Musikauffassung des rabbinischen Judentums.* Bern: Peter Lang, 2000.

[5] K. Nelson, *The Art of Reciting the Koran.* Austin: University of Texas Press, 1985.

[6] H. Hucke, "Toward a New Historical View of Gregorian Chant," *Journal of the American Musicological Society, Volume 33,* Chicago: University of Chicago Press, 1980.

[7] D. P. Biró and P. van Kranenburg. "A Computational Re-Examination of Béla Bartók's Transcription Methods as Exemplified by his Sirató Transcriptions of 1937/1938 and their Relevance for Contemporary Methods of Computational Transcription of Qur'an Recitation," in *Proceedings of the Fourth International Workshop on Folk Music Analysis,* Istanbul, 2014.

[8] P. van Kranenburg, Dániel Péter Biró, Steven R. Ness, and George Tzanetakis, "A Computational Investigation of Melodic Contour Stability in Jewish Torah Trope Performance Traditions," in *Proceedings of the International Society on Music Information Retrieval (ISMIR2011) Conference*, pp. 163–168.

[9] D. P. Biró, *Al Ken Kara (That Is Why It Was Called).* Brühl, Edition Gravis, 2024.

[10] D. P. Biró, *Scholium Secundum.* Brühl, Edition Gravis, 2022.

[11] L. Ibsen al Faruqi, "The Cantillation of the Qur'an", *Asian Music*, Vol. 19, No. 1, 1987.

[12] A. Yūsuf Ali, *The Holy Qur'ān, Text, Translation and Commentary*, Amana Corp., 1989.

[13] B. Wheeler, "Arab Prophets of the Qur'an and Bible," *Journal of Qur'anic Studies*, vol. 8, no. 2, pp. 24–57.

[14] Rouen, Bibliothèque municipale, 248 (olim A. 339). Praha (Prague), Národní knihovna České republiky (National Library), XIV.B.13.

[15] R. Weber, *Biblia Sacra. Iuxta Vulgatam Versionem.* Stuttgart: Deutsche Bibelgesellschaft, 1994.

[16] P. J. Bearman et al. (eds.), *Encyclopaedia of Islam*, Second Edition, Brill Online, 2014, https://referenceworks.brill.com/display/db/ei1o (accessed April 2, 2024).

[17] A. Cassidy, "Constraint Schemata, Multi-axis Movement Modeling, and Unified, Multi-parametric Notation for Strings and Voices," in *Search, Journal for New Music and Culture* 10 (2013). Available: http://www.searchnewmusic.org/cassidy.pdf (accessed November 29, 2022)

[18] B. de Spinoza, *Ethics*. Introduction by S. Hampshire, transl. by Edwin Curley, London: Penguin Books, 1996.

[19] "Gematria" *Encyclopedia Britannica*, https://www.britannica.com/topic/gematria.

[20] A. Kasher and S. Biderman, "Why Was Baruch De Spinoza Excommunicated?", https://www.tau.ac.il/~kasher/pspin.htm (accessed on November 29, 2023).