Style Modeling for N-Part Automatic Harmonization

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ABSTRACT

The following research proposes a framework for the automatic harmonization of melodic material in user specified musical styles. Harmonic style is defined using a mixed model of contrapuntal properties, probabilistic melodic and harmonic parametrization, corpus based analysis and state space querying. Experimental results demonstrate the model can satisfy species counterpoint requirements as well as provide the means to synthesize diverse, categorizable musical textures by meta-parameters.

1 Introduction

Harmonization, the process of composing melodies played simultaneously, is a fundamental element of musical style. Harmonic style can be informally defined by the relationships between respective lines and the relationship of notes within each line. Contrapuntal, harmonic and melodic properties of musical material have been used to describe these relationships. In different musical contexts, the relative importance and usage of these concepts varies. Thus successful harmonic solutions in a specified style are assumed to have similar properties.

In the Section 2, an overview of the prior work is described. Section 3 outlines the system architecture. In Section 4, operation of the model is detailed and Section 5 evaluates the model's performance. Section 6 discusses areas of further research.

2 Prior Work

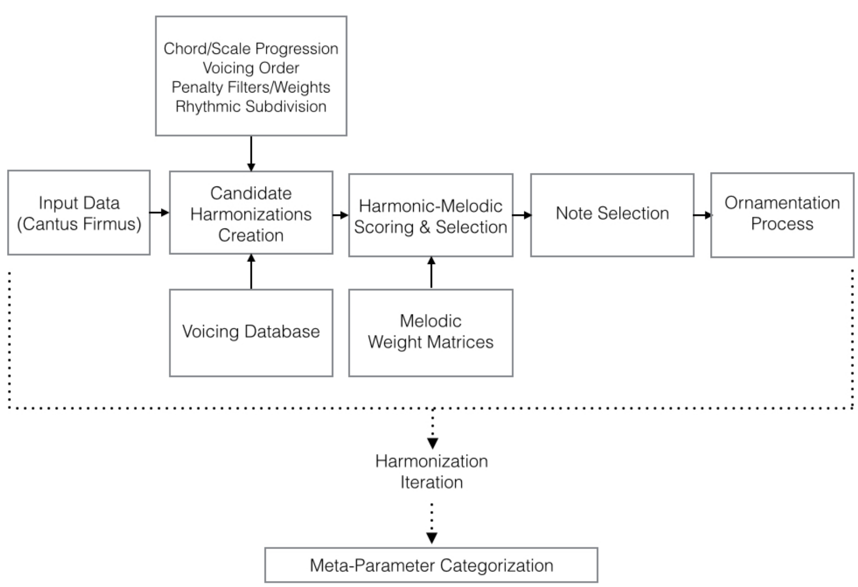
In the literature regarding auto-harmonization, a primary objective was to create proper counterpoint exercise solutions, usually up to 5 parts. Associated algorithms often approached harmonization non-linearly, generating harmonies by iterating through a melody or 'cantus firmus' from end to beginning, with 'backtracking' or 'looking' ahead' to ensure solutions adhere to strict 'Palestrina-style' criteria (Schottstaedt, Hiller, Isaacson, 1989). A strength of such a system is that the parameters (parallel/hidden octaves etc.) are musical in nature and thus easily comprehensible to a musician/composer. Furthermore, since the concepts are theoretical, no analysis of musical data is required. However, this strategy requires melodic material to be composed prior to harmonization and thus constrains the possibility of real-time auto-harmonization or other generative compositional processes, where the input melody (aka 'cantus firmus') is composed concurrently. Another limitation is that even 'proper' solutions can qualitatively lack in musicality. Other models attempt to introduce melodic interest by probabilistically influencing melodic motion (Farbood, Schoner, 2001). Probabilistic behavior has also been derived from analysis of music such as Bach Chorales. These corpus based statistical models successfully produce imitative musical results, however the design and solutions are often constrained to specific training data. The objective for this model was scalability to an arbitrary number of voices and a flexibility to produce harmonizations of any style. Aside from an optional non-linear ornamentation phase, this model has a linear design with a goal of realtime usage.

3 System Architecture

3.1 Component Diagram

A harmonic style is defined and generated with the following components: voicing tables, harmonic, melodic and contrapuntal metrics, melodic probabilities, ornamentation and combinatorial search by meta-parameters. The following section will begin with the component descriptions in the order that they are used in the harmonization process. For every note input, harmonization candidates will generated and analyzed by metrics that inform the best choice of notes, given a specified criteria. Melody harmonizations can then be batch rendered and searched based on specific meta-parameters, allowing the user a meaningful way to navigate the harmonic solutions.

Figure 1: Harmonization Components Flow Diagram



3.2 Voicing Table

Vertical note ‘voicings’ are important in defining harmonic styles. For instance, only root and first position triads are found in traditional species-style counterpoint, while second position tetrachords are frequently found in early 20th century impressionist music. The vertical arrangement of notes can be described as a set of intervallic relationships in a given mode/scale. This abstraction enables the definition of harmonic behavior independent of mode. For instance, any three-note root position triad can be expressed as two modal steps (eg. C,E,G = [2,2]), whereas the third tetrachord of Ravel’s String Quartet is 3 modal steps (eg. E,C,G,A = [2,3,6]). Tables of voicings can be associated and conditionally utilized to satisfy sequential requirements for a harmonic style. To satisfy cadential requirements of first species counterpoint, there are four distinct voicing tables for harmonizing the first, middle, penultimate and final notes of a melody. For chorale emulation or impressionist string quartet textures, larger voicing tables sourced from a corpus of music could be used to approximate a style’s harmonic properties. In two-voice first species counterpoint, there are approximately 33 possible voicings. In a more complex style such as Bach’s chorales, there are roughly 81 possible voicing used.

3.3 Harmonization Candidate Creation

For every note input, a state space is created consisting of harmonic candidates derived from specified voicing tables. Each voicing table is transposed by the input note, mode and voice order to generate associated pitch classes that will be analyzed in the harmonization candidate selection process. Compared to using combinatoric voice leading rules to create vertical sonorities, using smaller sets of transposed voicing tables is comparatively scalable as the number of voices increase. Furthermore, this method allows a wide variety of different harmonies without changing the structure of the model.

3.4 Harmonic Melodic Scoring and Selection

Once the list of voicing candidates has been created, selections are chosen based on harmonic, contrapuntal and melodic metrics.

3.4.1 Contrapuntal and Harmonic Metrics

As counterpoint practices evolved, it eventually became codified. This codification was used to evaluate adherence to the strict ‘species’ style developed by Fux in the 1700’s (Fux, 1725). Accordingly, contrapuntal observations can be used to create metrics describing harmonic behavior between melodic lines. In this method, every time a note is input, specified metrics are calculated and considered when selecting a harmonization candidate. Harmonic styles can be parameterized by using these metrics to select voicings deterministically and or probabilistically. For instance, parallel motion between perfect consonances is avoided in two-part first species counterpoint, however the same motion is acceptable and frequent in upper voices of four-part Bach chorales. Specifying the degree of importance for a particular behavior can be used when defining a harmonic style.

The following metrics are collected every time a note is input:

Figure 2: List of Melodic and Counterpoint Metrics Calculated for Every Harmonic Candidate

Counterpoint Metric	Value Range	Melodic Metric	Value Range
Parallel Octaves Count	0-N	Unpermitted Melodic Intervals	0-N
Parallel Fifths	0-N	Melodic Leaps	0-N
Parallel Fourths	0-N	Melodic Tritone Outlines	0-N
Tritone in the Lowest Voice	0-1	Skips in the Same Direction	0-N
Tritone Count	0-N	skips in the same dircection, 2nd leap shorter	0-N
Hidden Octave Count	0-N	Repeated Notes in Same Voice	0-N
Hidden Fifths	0-N	Melodic Probability Index	0 -1
Hidden Fourths	0-N	Minimum Melodic Span	0 -N
Consecutive Perfect Intervals	0-N	Minimum Melodic Span	0-N
Hidden Perfect Intervals	0-N	Has a Climax Note	0 -1
Harmonic Repetition Count	0-N		
Span Between Lowest/ Highest Note	0-N		
Is a Dominant Chord	0-1		
Is a Dominant Resolution	0-1		
Contrapuntal Index	0 - 1		

3.4.2 Contrapuntal Index

A useful way of differentiating harmonic candidates is to identify the amount of parallel, contrary and oblique motion between all voices. A ‘contrapuntal index’ is the average Parsons Code of a harmonic motion, where a value of 1 is ascribed for every instance of contrary motion, oblique motion to 0, parallel to -1. This index enables voicing candidates to be evaluated as a spectrum from maximally contrapuntal to strict parallel motion. Each voicing is scored, and compared to the other candidates’ metrics, resulting in the ability to generate harmonizations. When a harmonization of an input melody is complete, the entire harmonization is scored with the same contrapuntal index resulting in the ability to navigate the solutions contrapuntally.

3.4.3 Melodic Metrics

A sequence of vertical note voicings can be interpreted horizontally as melodies. Once a list of voicing candidates has been created for an input note, melodic behaviors emerging from the potential candidate can be evaluated. Like contrapuntal metrics, melodic metrics are collected every time a new note is input. See Figure 2 for a list of horizontal metrics.

3.4.4 Melodic Probability Tables

In order to influence melodic behavior independent of vertical considerations, this model accepts input tables of values that represent the probability of a melodic interval based on the preceding melodic interval(s). For instance, leaps can be constrained to a given range and step-wise motion can be favored. Probability tables can be generated to define specific melodic behavior or can be derived from a corpus-based analysis. Probabilities for each voice are summed and compared to the other candidate's probabilities during the candidate selection process. For this implementation, a MIDI file database of Bach chorales was analyzed and transformed into melodic probability tables. In the current model are four melodic probability tables derived from analysis of Soprano, Alto, Tenor, and Bass voices. Any probability table can be used to define the melodic probabilities of any voice in the harmonization, enabling the user to individually experiment with each melody's properties.

3.4.4 Voicing Candidate Selection

Once every metric has been calculated for each candidate for a given note, the user can select criteria to help reduce the number of potential candidates. One can remove candidates by thresholding above or below any metric. For instance, one can remove candidates resulting in parallel octaves and also ones that have a negative contrapuntal index to ensure oblique and contrary motion. Metrics can also be normalized and used probabilistically with the option to scale their relative degree of importance in candidate selection. For instance, the occurrence of hidden fifths could be scaled as more important of a penalty than instances of un-permitted melodic intervals. Based on these user specified criteria, each candidate voicing is assigned a probability that can be used when selecting a voicing from the list of options. In the event user specified thresholding is too strict for any of the supplied voicings, the most probable candidate based on the thresholding/weights will be selected. This ensures that the algorithm will always return the best harmonization available based on the user specified criteria. Furthermore, it prevents prohibitively strict criteria from removing all possible candidates.

3.5 Ornamentation and Non-Harmonic Tones

Non-harmonic tones and melodic ornamentations are also indicators of harmonic style. For instance, choral music will frequently have non harmonic suspended chord tones, whereas harpsichord music can be characterized by the use of anticipatory notes and trills. Ornamentation can be created linearly by conditional voice sequencing, however some ornamentation is best created non-linearly. Although a more complex linear ornamentation process was initially examined and attempted in this model, experimental results proved underwhelming and the number of possible states was unscalable with increased voices. Furthermore, most ornamentation is dependent on the relation between preceding and following notes. Anticipating candidates without assumptions about future melodic material make the state space search for adequate solutions prohibitively large. The non-linear process takes place after all note inputs have been harmonized. Ornaments and their conditions can be defined and used probabilistically. For each voice, one can select the probability of an ornament occurring when an opportunity arises. For instance, a passing tone can be added between a leap of a third, and a chromatic passing tone can be added between melodic motion of a major 2nd. For each ornament type, the user can specify unique probabilities that a given ornament will be added to the melody. This probabilistic way of choosing ornamentation ensures that distinct ornamentations will occur each time the process is run. When batch rendering harmonizations, the user is able to add unique ornamentations to at their own discretion.

3.6 Batch Rendering: Meta-Parameter State Space Search

Every iteration of the harmonization process will lead to a unique result so long as the voicing tables are sufficiently large and the metric constraints aren't prohibitively strict. Each harmonization will slightly deviate from essentially similar metrics. Every time the harmonization process is run on a sequence of notes, meta-parameters are tracked by the harmonizer. A list of melodies can be created, sorted and categorized by their meta-parameter metrics. See figure 3 for metric definitions:

Error index - The sum of metrics for all chosen voicing candidates

Contrapuntal_index - The sum of contrapuntal indexes

Transition_table_index - The sum of metrics for all chosen voicing candidates

Hasclimaxsum - The sum of climaxes for all chosen voices

Maxspan - The maximum distance in semitones between the highest and lowest voice

Numleaps - The number of leaps in all voices of a harmonization

The following metrics are enables the user to navigate harmonizations with specific properties. For instance it might be important for every melody in the harmonization to have a climax but have very few leaps.

4 Model Operation

As mentioned, the process of creating, scoring and choosing a harmonic candidate occurs for each note input. Thus, for each note input a *selectNote* method is called to return a selected voicing of notes based on the following argument inputs:

Voice Order - defines the arrangement of notes in relation to the input note.

Voice tables - defines the possible vertical candidates and the number of parts in the harmonization.

Melodic Probability Tables - Assigns the probability table to be used when selecting voicing candidates.

Note input - a PitchClass input to harmonize. Ideally should belong to the mode selected.

***Mode/Scale input* -** The mode to use when harmonizing the PitchClass.

Duration associated to input note - Duration of input note in seconds.

List of metrics to threshold - A list indexes representing metrics used to remove harmonic candidates.

List of thresholding values for specified metrics - Reject any harmonic candidate with metrics above the threshold(s), negative values threshold reject any values below.

List of probabilistic metrics to consider for candidate selection - A list indexes representing metrics used to calculate the probability of a harmonic candidate being selected.

Probability weights for specified metrics - A list of values that scale associated metrics importance when calculating the probability of a harmonic candidates' selection.

Ornamentation Event Probability - The probability of an ornamentation occurring given the opportunity.

Ornamentation probability table - A list of numbers between 0-1 representing the probability of a specific ornament occurring.

Once the *selectNote* method is run for each note in a melodic sequence, the harmonizations can then be collected and rendered as simultaneously played melodies. The user can then elect to create a database of harmonization solutions, and sort collect by particular meta-parameters.

5 Evaluation

Experimental results demonstrate the model's ability to generate harmonizations in a variety of styles. The probability weights and using of specific voicing tables is effective in defining and manipulating harmonic style. However, given the model's linear and probabilistic nature, it is possible that some harmonizations will not strictly abide by all specified criteria. In that event, the least offending option is returned. This reduced accuracy is a tradeoff for a linear process that will guarantee to give you a harmonic solution with the same speed every time. Given the ability to generate hundreds of harmonizations quickly, a user can sort through options to find the best melody out of a selection. This process is of compositional value, because some "poorly scoring" harmonizations are qualitatively more musical than better scoring harmonizations. The model also allows for unique synthesis of different harmonization properties. For instance, five note voicing 'So What' chords are primarily seen used with parallel motion, however the user can apply species style voice leading constraints for the creation of entirely new textures. All of the musical examples below in Section 7 are different harmonizations of the same melody. Composed by Heinrich Schenker, this melody was written for the use of practicing counterpoint, and serves to illustrate the various styles the model is capable of generating.

6 Discussion

Given increased computational power, generating and storing large numbers of harmonizations enables the composer to use the tool according to their own creative needs. For example, this process can change the process of harmonization from a manual attempt at identifying an optimal compositional choice to a search/query paradigm where relevant solutions can be identified. This model also provides the composer with the ability to generate music that they might not conceive with their own abilities. Furthermore, the model's ability to create many relative options can provide a means of increasing the degree of belief in a given compositional choice.

The model is capable of harmonically diverse styles using the available parameters. However, this highlights a current shortcoming: The model requires very explicit understanding and definition of the style that one is attempting to achieve. Currently, a user must input specific voicings, voice sequencing logic and parameter values to successfully define a harmonic style. It will be important for this model to add a thorough database of voicing and voicing sequence information to streamline the user experience. Furthermore, definitions of style might not be accurate due to lack of user knowledge. A current area of research is analyzing musical data to 'tune' the parameters by using the metric analysis to develop probabilistic metrics for specific styles. For instance, the prevalence of hidden fifths in Poulenc's choral music could be used to determine the likelihood of note candidates with hidden fifths for auto-harmonizations. Similarly, a more efficient or streamlined way to conditionally sequence harmonies could be a future area of study. One specific direction is to manage chord progressions via a tonal harmony model. Another direction is to create probabilities for a given voicing based on it's usage for a given melodic interval in the input note melody. Even at this foundational development stage, the model is still every flexible and has already served me well in a variety of musical contexts.

6.1 Optimization considerations

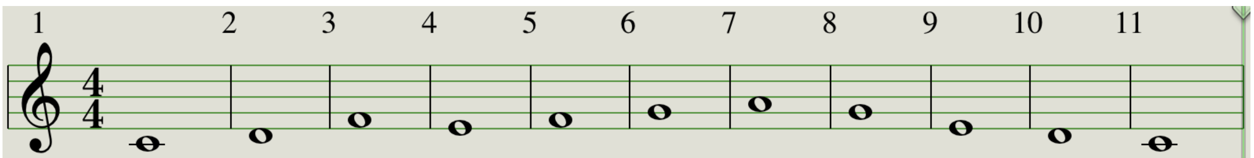
As each metric was calculated for each note input, the processing time steadily increased beyond real-time capability. An optimization process could speed things up, such as selectively calculating metrics and limiting the number of voicing candidates. The selection process now ranks all options against each other before making a choice, however the process could be sped up by returning the first permissible option. For increased accuracy, one could add a look ahead or behind to make corrections for selected candidates that scored poorly.

6.2 Conclusion

The current model has demonstrated the ability to synthesize a wide variety of harmonic styles. Given the model has both linear and non-linear functionality, a composer is able to use the model according to their creative prerogatives. The framework is also expandable to add additional stylistics considerations as they are identified.

7.0 Musical Examples:

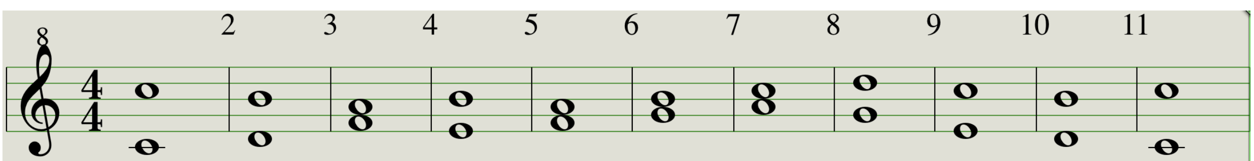
Cantus Firmus Line (Schenkar)



Average values of 250 harmonizations:

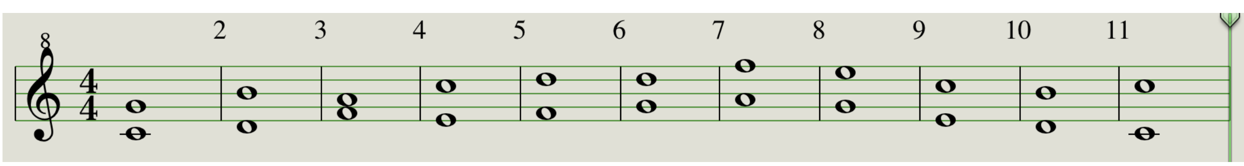
[Error Index: 5.992, contrapuntal index: 4.472, melodic probability index: 2.5443168911028, Has Climax: 0.828]

Example 1 -Harmonized line, low error endex:



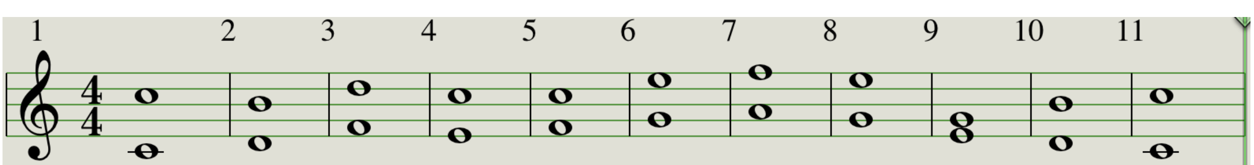
[Error Index: 1, contrapuntal index: 6.0, melodic probability index: 2.0, Has Climax: True]

Example 2 - Less contrapuntal, higher melodic probability:



[Error Index: 2, contrapuntal index: 4.0, melodic probability index: 4.0235005368922, Has Climax: True]

Example 3 - Less contrapuntal, slightly higher melodic probability:



[Error Index: 2, contrapuntal index: 4.0, melodic probability index: 4.0196817805859, Has Climax: True]

2 Part Second Species:

Average of 300 Harmonizations:

[Error Index: 16.54, contrapuntal index: 14.27, melodic probability index: 24.280086543578, Has Climax: 0.763333333333333, number of Leaps: 7.83]

Example 4

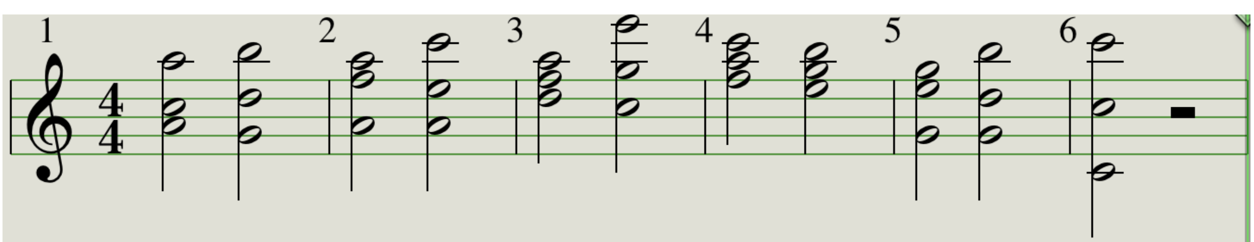
[Error Index: 12, contrapuntal index: 15, melodic probability index: 22.527305416136, Has Climax: True, number of Leaps: 9]

Three Part First Species:

Average values of 200 harmonizations:

[Error Index: 20.025, contrapuntal index: 5.415, melodic probability index: 5.6385545992941, number of climaxes: 3, number of leaps: 6]

Example 5



[Error Index: 14, contrapuntal index: 6.0, melodic probability index: 8.1323515876668, Has Climax: True for all three voices, number of leaps: 6]

5 Part Voicing - ‘So What’ chords, quartal,7th and 9th chords’) with Ornamentation on Every voice

Example 6

Citations:

J. J. Fux. *Gradus ad Parnassum*. Vienna, 1725.

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