

A HARMONY-BASED HEURISTIC MODEL FOR USE IN AN INTELLIGENT TUTORING SYSTEM

JOHN WILLIAM SCHAFFER

INTRODUCTION

Teaching many musical tasks often requires a level of subjective understanding lacking in much traditional drill-and-practice computer-assisted instruction (CAI). Fortunately, advances in artificial intelligence now have made possible the development of *Intelligent Tutoring Systems* (ICAI) based on domain-specific, knowledge-based representational strategies. Most existing examples of such systems have been developed on expensive mainframe computers, thus severely hampering their dissemination. The power of today's microcomputers, however, has finally enabled the development of intelligent systems structured around accessible technology. This paper will examine the three key elements central to the development of a working system for tutoring the concepts of harmonic progressions: 1) the knowledge representational scheme; 2) the heuristics, or basic organizational strategies, for bringing a higher level of meaning to the knowledge; and 3) the inference engine developed to coordinate the interaction of these rules.

OVERVIEW

The program *HARMONY COACH* is an amalgamation of three interrelated coaching modules that were originally developed to demonstrate the feasibility of creating an intelligent tutorial for the coaching of music theoretical skills within a widely accessible microcomputer environment (Schaffer 1988). Two of the modules coach the writing of non-modulatory, tonal harmonic progressions, aiding the student in the creation of an acceptable harmonic progression based on either an unfigured bass line or melody. The third module coaches the student in the voice-leading of any of their previously harmonized exercises using a traditional four-voiced model. The remainder of this paper will focus on the domain representation of those modules tutoring harmonic progressions.¹

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Any well-designed knowledge base must contain sufficient information to represent effectively the complete domain of the knowledge being tutored. The implementation of such a structure, however, also requires the development of appropriate heuristic strategies to utilize and access the representative knowledge effectively. Unfortunately, since expert systems are only capable of encapsulating facts, rules, and relationships within and between each other, and since our understanding of harmony and its numerous intricacies is not wholly solidified, the knowledge domain of the tutorial, by definition, cannot be complete. It can, however, be quite comprehensive within the scope of existing precepts. Obviously, the coach cannot analyze thoroughly all extant diatonic compositions, since undefined anomalies will always appear. In reality this is not a serious hindrance. Since the tutorials are designed to teach and not analyze, they do what most of us do all the time: we teach those things that are definable first, saving the anomalies for later. Intelligent tutorials cannot always deal effectively with the intangible aspects, but they can coach the normative conventions.

Defining an expert model also can prove problematic, since every theorist tends to view harmonic practices through their own tinted glasses. Ideally, one should be able to put five theorists in a locked room and have them pool their collective knowledge with one resulting point of view. Human nature being what it is, however, this approach would most likely be unproductive! Traditional textbooks, on the other hand, do exhibit a surprisingly high level of correspondence. To test the effectiveness and thoroughness of the knowledge base, as well as the ability of the program to actually coach students in their comprehension, textbooks were selected as the fundamental source to define the expertise of the tutorials. Six books, each representing a distinctive approach, were digested, correlated, and codified into a single comprehensive rule base—comprehensive, that is, within the confined domain delineated by the textbook precepts. The textbooks employed were Allen Winold's *Harmony: Patterns and Principles* (1986), Allen Forte's *Tonal Harmony in Theory and Practice* (1979), Stefan Kostka and Dorothy Payne's *Tonal Harmony* (1984), Edward Aldwell and Carl Schachter's *Harmony And Voice Leading* (1989), Robert Ottman's *Elementary Harmony* (1983), and Bruce Benward's *Music: In Theory and Practice* (1985).

THE KNOWLEDGE STRUCTURE

HARMONY COACH is built on a knowledge base designed around a three-tiered heuristic inference engine. The lower two levels of the model

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represent diatonic tonal harmonic progressions—one expressing the broader concept of classifying harmonies into general chord classes, the other structuring the lower levels of information specific to distinctive chord groups. This part of the rule base contains all the factual and relational information necessary to represent the knowledge domain of the program.

This two-level “patterning” scheme forms the foundation for modeling common and effective student strategy for learning complex musical tasks. Allen Winold, in the preface to *Tonal Harmony: Patterns and Principles* (1986), describes the approach used in the book:

... a patterned approach ... involves the presentation of a limited number of basic chord progressions as the core materials. ... After learning to analyze, write, play, and hear these progressions in their basic form, the student learns to adapt them and to integrate them into longer, more varied musical contexts. This approach is similar to modern methods of teaching foreign languages, in which students learn basic phrases and then learn to vary them and use them in longer patterns of thought (1986, vii).

Specifically, by starting with small atomic elements and coalescing them into larger conceptual packets—or patterns—a student is able to reduce the amount of information required at any given stage, thus simplifying the conceptualization process. Similarly, just as patterns are formed and associated by students during the course of learning a complex task, a knowledge structure designed to coach those same students also can be defined around such principles. Clearly, a well constructed cognitive learning strategy should translate into an effectively organized expert model capable of the same sort of flexible, yet simple, level of comprehension.

Unlike the lowest two levels, which embody the factual and relational knowledge of the program, the third level constitutes a forward-referencing inference engine operating on a reverse-looping design. This level is employed to trigger control of those particular knowledge structures appropriate for dealing with a given student query from the lower two levels.

THE THREE-TIERED MODEL

The first, or lowest, level asserts facts and precepts that define specific aspects of harmonic structure and interaction. These precepts, in essence,

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represent a collection of all those commonly held tents that make up the bulk of most theory textbooks.² Through evaluating the cumulative materials of the five theory texts previously mentioned, eleven general rule categories defining the textbook conventions of diatonic (i.e., non-modulatory) harmonic progressions emerged. A list of these precepts is given in figure 1.

Figure 1. Harmonic Precepts:

1. phrase-level harmonic motion,
2. general chord classifications,
3. root progressions,
4. first-inversion functions,
5. second-inversion functions,
6. general seventh-chord functions,
7. dominant-seventh chords,
8. other sevenths,
9. harmonic rhythm,
10. harmonic succession, and
11. linear harmonic functions.

Many of these categories coincide on a one-to-one basis with typical chapter headings and frequently represent closed precepts. Other categories exemplify an amalgamation of seemingly disparate facts pulled from various topical areas. For example, precepts about dominant-seventh chords can be relatively self-contained. The harmonic and voice-leading functions of these chords are tightly defined and, within the limited domain of the tutorials, tend to operate consistently regardless of their contextual situation. On the other hand, precepts defining the nature of inversions, for example, are often strongly contextual and must rely heavily on precept interaction, forcing the inference engine to monitor closely other factors in a given exercise. For example, a cadential tonic six-four chord functions quite differently than a passing dominant six-four chord. Similarly, the bass note of a first-inversion triad may have a strong predilection to resolve by step unless the chord following it represents a different formulation of the same harmony. In this case the resolution would likely be by leap. In many cases, precepts at this level aim at being distinctly non-chord specific, generalizing instead on classes of chords. *HARMONY COACH* uses the four class categories defined by Allen Winold (1986). Specifically, these are Tonic class, Dominant class, Subdominant class, and Linear class. (A

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complete listing of all the first-level precepts appears in Table 1 at the conclusion of the article.)

The second (or middle) heuristic level, acts essentially as a traffic manager for the first-level precepts. Once a specific chord is assigned to a chord class, the primary function of this level is to coordinate which level-one precept(s) should be applied and tested for any given situation and to determine the order in which they will be evaluated (or "fired"). Heuristic precepts at this level are designed specifically to function with adjacent chord pairs (discussed later). Since the third, or highest, heuristic level deals primarily with interrelationships between multiple harmonies, it is essentially the job of the middle-level precepts to coordinate the individual chord-pair functions that subsequently are linked together during the final stage. Figure 2 shows one example of a middle-level precept. (A complete listing of all middle-level heuristics appears in Table 2 at the conclusion of the article.)

Figure 2.

PRECEPT 11.1a: A root-position Tonic-Class triad may harmonize the given bass note...

IF a chord moves to another chord with the same root **AND** rules...

(2.1a [Tonic-class chords may move to chords of any class] **AND** 4a [a progression from any root-position chord to the same chord in first inversion is acceptable] **AND** 9 [two adjacent chords sharing the same root must not be separated by a bar line] **AND** 1a [the last chord of a progression must be a tonic, dominant, or submediant] are observed...)

OR two chords are **NOT** the same **AND** rules...

(2.1a [Tonic-class chords may move to chords of any class] **AND** 1a [the last chord of a progression must be a tonic, dominant, or submediant] are observed.)

[(same chord **AND** 2.1a **AND** 4a **AND** 9 **AND** 1a)

OR (NOT(same chord) **AND** 2.1a **AND** 1a]

This example reads as follows: A root-position Tonic-Class triad may harmonize the given bass note **IF** the chord moves to another chord with the same root **AND** if it follows the rules controlling the motions of a (T)onic-Class chord to chords of the same chord class **AND** it progresses from a root position to the same chord in first inversion **AND** the two adjacent chords sharing the same root are not separated by a bar line **AND** if either chord is the last chord of a progression (i.e., a cadence), it must be a tonic, dominant, or submediant; **OR** the two chords do **NOT** share the same root **AND** it follows the rules controlling the motions of a (T)onic-Class chord to chords of the different chord classes **AND** if either chord is the last chord of a progression (i.e., a cadence), it must be a tonic, dominant, or submediant.

It might be obvious to assume that there are four precepts such as these to define each of the four chord classes. Some situations, however, demand more specificity (for example, as stated earlier, a linear-class passing dominant six-four chord). Both chords are of the linear class, yet their functions cannot be united. Given this and similar situations, it seemed more productive to isolate various sub-class groups and to assign specific middle-level heuristics where appropriate. Since this specificity is critical to the ability of the knowledge base to respond effectively to student inquiries, the more finite each precept, the better able the program is to respond to individual queries.

Finally, the highest heuristic level triggers consultation decisions based on the location of a specific chord-pair choice within the context of a given exercise. As implied earlier, this level contains no specific factual knowledge. Instead, it functions to link the specifics of an actual exercise to the lower two levels of the rule structure. For example, regardless of chord classification (such as tonic or dominant), the positioning of a particular chord within a cadence, as opposed to elsewhere in a specific harmonic progression, might significantly affect which precepts need to be consulted. Additionally, the heuristics at this level must take into account previous successful student choices. Obviously, the selection of a particular chord at a given position within a progression will be more restrictive if an adjacent position is harmonized than if it is not. Since the Coach allows students to harmonize an exercise in any order they wish, it cannot assume that each chord choice will have immediate successors or predecessors present in the progression. Whenever a new chord is inserted into the exercise, existing chords on both sides of the entry are rechecked, taking into consideration the newest entry. This action insures that all previous choices are updated in relation to any new information in the knowledge base. If a previously acceptable harmonization now becomes problematic in relation to some new choice elsewhere in the progression, the student is informed of the

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problem and has the opportunity to correct it by changing either or both of the offending harmonies. (A listing of the highest-level heuristic appears in Table 3 at the conclusion of the article.)

In developing the heuristic strategies for this level, one significant problem became apparent immediately: how to develop a control heuristic that could coordinate the middle-level heuristics to account effectively and efficiently for a number of various situations. For example, a chord may appear at the beginning of the piece, in which case there will be no chord of preparation; likewise, the final chord of the exercise will have no chord of resolution. A harmony in the middle of the progression might or might not have a previously asserted harmony on either or both sides of it; and, if one of the adjacent notes is or is not harmonized, how many additional notes on either side of it are or are not harmonized. Unfortunately, the list of possibilities is extensive. To deal with this complex side effect, a forward-referencing, reverse-looping inference engine was developed that overcomes this problem rather directly. Recall that all middle-level heuristics are chord-pair referenced. In other words, each harmony is compared with one and only one other harmony at any given point—in most cases the chord of resolution. Designing the precepts around a forward-referencing scheme such as this eliminates much of the unnecessary complexities of a rule structure that must take into account all of the various situations outlined a moment ago. In this case, each precept needs to know only where it is going, not from where it is coming.

Conversant musicians, of course, should be able to see the weakness in this rather myopic view. If, however, the forward-referencing model is employed as part of a multiple, reverse-looping design that sequentially shifts the chord-pair reference point forward and backward, all of the notes necessary to evaluate the relevant portion of the progression are, in effect, covered. This heuristic approach effectively accomplishes the task of looking forwards and backwards from any point in the progression while maintaining the simplicity of the original forward-referencing model. Figures 3 and 4 will serve to clarify the process through several simple hypothetical examples.

Figure 3a represents a typical beginning melody the program might present to a student for harmonization. In this instance, the entire melody is preset to an initial harmonization of *null* (not currently harmonized). *HARMONY COACH* is explicitly designed to allow a student to begin anywhere. In this case, however, our hypothetical learner begins at the beginning by asserting a root-position tonic chord as harmonization for the melodic D natural shown in Figure 3b. The upper-level heuristic begins by calling the first relevant middle-level precept. Since all middle-level

functions deal with forward-referencing chord-pairs, the asserted chord is checked against the nest position. In this example, finding a *null* harmonization causes two actions to occur. First, every time a *null* is encountered, the note in question is checked in relation to the existing chord preceding it. Then, an attempt is made to see if it has the potential to support a harmonization suitable for the chord pair in question. Second, the control mechanism must reposition the reference pointer one position to the right and, then, check the next chord pair to insure that any of the hypothetical solutions to the first *null* are also capable of progression to the next harmony. In this instance, a second *null* in an adjacent position halts the forward succession of events and triggers a reverse-loop that moves the reference position from its current location two position to the left, ending up on the immediate predecessor to the original position on the first note. At this point another middle-level precept is called to deal with the new chord pair. Since no note exists prior to the first one, the process is halted and the program responds positively to the student.

Figure 3.

Figure 3 consists of five musical staves, labeled a) through e), each in G major (one sharp). The staves illustrate a process of identifying and resolving 'null' harmonizations in a sequence of notes.

- Staff a)** Shows a sequence of notes: G4, A4, B4, C5, D5, E5, F#5, G5. Below the staff, the word 'null' is written under the last four notes (C5, D5, E5, F#5).
- Staff b)** Shows the same sequence of notes. Below the staff, the word 'null' is written under the last four notes. Arrows point from the first 'null' to a box labeled '1) I' and from the second 'null' to a box labeled '2) null'.
- Staff c)** Shows the same sequence of notes. Below the staff, the word 'null' is written under the last four notes. Arrows point from the first 'null' to a box labeled '1) vi', from the second 'null' to a box labeled '2) null', and from the third 'null' to a box labeled '3) I'.
- Staff d)** Shows the same sequence of notes. Below the staff, the word 'null' is written under the last four notes. Arrows point from the first 'null' to a box labeled '1) V', from the second 'null' to a box labeled '2) null', from the third 'null' to a box labeled '3) null', and from the fourth 'null' to a box labeled '4) vi'.
- Staff e)** Shows the same sequence of notes. Below the staff, the word 'null' is written under the last four notes. Arrows point from the first 'null' to a box labeled '1) ii6', from the second 'null' to a box labeled '2) V', and from the third 'null' to a box labeled '3) vi'.

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Next, as in Figure 3c, the student asserts a root-position submediant chord as a harmonization for the second melody note. As in the previous example, a middle-level precept checks the chord pair in positions two and three. Any further forward references are halted after testing the *null* in position three and checking it against position four. Reverse looping is triggered again and the chord pair starting in position one is checked for acceptability.

As can be seen in Figure 3d the student next decides to jump ahead to the cadence and asserts a dominant chord in the penultimate position of the exercise. Again, a forward-reference check is made and halted at the *null* harmonization of the final chord. Reverse looping moves the reference point one position to the left and another check is undertaken. At this point, a *null* in the first position of the chord pair causes an additional reversal to occur, which, in turn, checks the forward-referencing progression from the root-position submediant in position two against the *null* in position three. This additional step is essential since any hypothetical solutions for harmonizing the E-natural in position three must form an acceptable progression with the existing chord preceding it. Two situations are possible at this point, both of which would stop the reverse looping. First, a *null* harmonization in position two would indicate a complete *null pair* between positions two and three. Further checking beyond this point would be unproductive, since the number of possibilities would expand exponentially, thus making any further concrete assertions unproductive. Second, the presence of a chord in position two, as is the case here with the previously asserted submediant, indicates that checking has already occurred between chord pairs to the left of this position, thus making any further checks at this level redundant.

Finally, as seen in Figure 3e, the student fills the gap by supplying a harmonization for the E-natural in position three. A forward reference checks position three against position four, then position four against the *null* in position five. A reversal occurs and position two is checked against position three. Finally, the student completes the exercise by supplying the tonic in the last position, the last checks are made and final evaluations are undertaken.

While this example is not meant to be comprehensive, it does show the working of the forward-referencing, reverse-looping heuristic at the most simple level. The same principle can also be applied to the examination of larger gestures or more complex problems. Keeping in mind the phrase-level domain of *HARMONY COACH*, however, such usage is limited to a relatively small number of precepts. Again, a simple example will suffice.

Figure 4.

Figure 4 consists of five musical staves, labeled a) through e), each showing a sequence of chords and their functions. The chords are: V, I, vi, ii⁶, V, vi, IV⁶, I⁴₆, V⁷, I. The staves illustrate different points of analysis and forward-referencing.

- a) Shows the sequence of chords with a box containing a question mark (?) above the final chord pair (V⁷, I).
- b) Shows the sequence of chords with a box containing a question mark (?) above the first chord pair (V, I).
- c) Shows the sequence of chords with a box containing a question mark (?) above the third chord pair (vi, IV⁶).
- d) Shows the sequence of chords with a box containing a question mark (?) above the fourth chord pair (I⁴₆, V⁷).
- e) Shows the sequence of chords with a box containing a question mark (?) above the fifth chord pair (V⁷, I).

Upon completion of an exercise such as the one shown throughout Figure 4, several checks might be undertaken to assess the overall performance of the student. One obvious point to examine might be the structural integrity of the phrase in terms of the final cadence, the early establishment of a key, and the motion from the incipit to the close of the phrase. The check begins when the third-level heuristics trigger those precepts designed to deal with phrase structure and organization. Figure 4a shows the precept beginning its check between the final chord-pair of the piece. Once satisfied that the cadence is in order, reverse looping takes place and the position pointer is moved to the initial note of the exercise, as shown in Figure 4b. At this point, forward-referenced chord pairs are examined sequentially until the precept is satisfied that the tonic of the exercise is established relatively early in the phrase. Again, only one check is required in this example. To insure that the student has written an exercise that exhibits a satisfactory balance between repetition and variety, yet does not contain an excess of cadential material, the precept begins a forward-referencing look at the intermediary chords to determine if any additional dominant harmonies occur. If the chords do appear, their possible function in the progression is examined. In Figure 4c, the search encounters a dominant fairly early on. Immediately, as in Figure 4d, the position pointer is moved forward to position five and a second forward-referenced search is undertaken to

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determine the nature of the remaining progression. This time, no tonic is found prior to encountering the final cadence. A quick scrutiny of the intervening harmonies determines that a larger-scale dominant prolongation has occurred between positions five and nine. Finally, satisfied that the cadential properties of the exercise are in order, the precept re-positions the pointer to position five—the beginning of the dominant prolongation—and initiates a simple forward-referencing, reverse-looping examination of the remaining harmonies. The process continues in this manner until all desired assessments are made.

CONCLUSIONS

The heuristic inference engine in the *HARMONY COACH* is sufficient to allow the program to fulfil successfully the basic criteria so essential to the functional ability of the program to coach. First, the program contains the domain knowledge in a manner consistent with our recognized teaching tool; second, it can function to recreate student learning processes by representing its knowledge in a manner similar to that of a pseudo-student; and finally, it can access the domain knowledge to solve domain problems, explain the logic behind *how* the problem was solved and *why* the choice is acceptable, and similarly explain *why* a choice is not acceptable, as well as explain the logic underlying that assessment.

As mentioned earlier, since the inference engine in *HARMONY COACH* functions in a teaching environment aimed specifically toward the development of relatively low-level skills, it does not explicitly include extensive knowledge on larger-scale harmonic structures. As was shown in the examples above, however, the pattern approach of grouping multiple smaller structures into a reduced number of larger patterns—a concept so integral to the heuristic model—would certainly be capable of supporting such expansion.

Finally, while the particular knowledge base being discussed here is designed specifically for the storage and dissemination of principles related to harmonic progressions, the three-tiered organizational structure of pattern building has shown itself to be sufficiently flexible to allow for its use in numerous musical applications. I hope the information in this paper can be of some value to others interested in the application of expert system technology to the study and pedagogy of music.

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Table 1. Rules of Harmonic Progressions.

Regarding basic harmonic motion, the following precepts apply:

- 1a: The last chord of a progression **MUST** be a tonic, dominant, or submediant chord.
- 1b: If the last chord of a progression is a tonic then the next to last chord **MUST** be a dominant, subdominant, or leading tone.
- 1c: If the last chord of a progression is a submediant then the next to last chord **MUST** be a dominant chord.

Regarding incipits (beginnings), the following precepts apply:

- 1.1a: It is **PREFERRED** but not essential that the first chord of a progression should be a tonic or dominant chord.
- 1.1b: If the first chord isn't a tonic then the first bass note capable of supporting a tonic chord **SHOULD** be harmonized by a tonic chord.

Regarding chord classifications, the following precepts apply:

- 2a: Tonic and submediant chords (root position & 1st inv.) are considered to be (T)onic-class chords.
- 2b: Dominant and leading-tone chords are considered to be (D)ominant-class chords.
- 2c: Subdominant and supertonic chords are considered to be (S)ubdominant-class chords.
- 2d: Mediant and 2nd-inversion triads are considered to be (L)inear-class chords.

Regarding general motion between classes, the following precepts apply:

- 2.1a: (T)-class chords move to chords of any class.
- 2.1b: (S)-class chords **SHOULD** move to (D)-class chords. A subdominant chord may also move to a tonic chord.
- 2.1c: (D)-class chords **MUST** move to (T)-class (or V-IV⁶ in minor).
- 2.1d: A chord of one class **MAY** move to a different chord of the same class.

NOTE: Each (L)-class chord moves according to its own precept(s).

Regarding Preference of root motions, the following precepts apply:

- 3a: Root motion down by a 5th is preferred to all other motions.
- 3b: Root motion up by a 2nd is preferred to all motions except those of precept 3a.
- 3c: Root motion down by a 3rd is preferred to all motions except those of precepts 3a-b.

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- 3d: Root motion up by a 5th is preferred to all motions except those of precepts 3a-c.
- 3e: Root motion down by a 2nd is preferred to all motions except those of precepts 3a-d.
- 3f: Root motion up by a 3rd is least preferred.

Regarding first-inversion chords, the following precepts apply:

- 4a: A progression from any root-position chord to the same chord in first inversion is ACCEPTABLE and DESIRABLE.
- 4b: A progression from any 1st-inversion chord to the same chord is ACCEPTABLE, but NOT PREFERRED.
- 4c: A progression from any 1st-inversion chord to a chord whose bass note lies step-wise above or below the current bass note is both ACCEPTABLE and DESIRABLE.

Regarding specifically the first-inversion mediant and submediant:

- 4.1a: These chords should occur ONLY in descending step-wise progressions (see specific precepts for each chord).

Regarding the cadential six-four, the following precepts apply:

- 5a: A 2nd-inversion tonic triad MUST move to a root-position dominant or dominant-7th chord.
- 5b: A 2nd-inversion tonic triad should ONLY be preceded by a (T)onic- or (S)ubdominant-class chord, NEVER by a (D)ominant-class chord or another 2nd-inversion tonic chord.
- 5c: It is preferable for a 2nd-inversion tonic triad to be approached by step-wise motion in the bass.
- 5d: A tonic six-four chord should ONLY appear as part of the final cadence of the phrase, but NEVER as the last chord.

Regarding the rhythmic placement of a cadential six-four chord:

- 5.1a: A 2nd-inversion tonic triad MUST appear on a stronger beat than that of the next chord.

Regarding metric stress (accent), the following precepts apply:

- 5.2a: Beat one of a measure is ALWAYS the strongest.
- 5.2b: The last beat of a measure is ALWAYS the weakest.
- 5.2c: In quadruple meter, beat three is stronger than beat two.

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Regarding triad /7th-chord motion, the following precepts apply:

- 6a: Motion from a triad to a 7th chord built on the same root is ACCEPTABLE.
- 6b: Motion from a 7th chord to a triad built on the same root is NOT ACCEPTABLE.

Regarding the dominant seventh, the following precepts apply:

- 7a: The V⁷ chord MUST resolve to a (T)onic-class chord or to another dominant-7th chord.
- 7b: A tonic resolution of the dominant-7th chord is preferred to a Submediant (deceptive) resolution.
- 7.1a: When a dominant-7th is approached by scale-degree 5 in the bass, the preferred preparation is by a V⁽⁷⁾ or I^{6/4}.
- 7.1b: When a dominant-7th is NOT approached by scale-degree 5 in the bass, common preparations include the supertonic, subdominant, and submediant.

Regarding dominant-seventh chords in inversion:

- 7.2a A 1st-inversion dominant 7th MUST resolve up by half-step to a root-position tonic chord.
- 7.2b: A 2nd-inversion dominant 7th MUST resolve by step to either a root-position or 1st-inversion tonic chord.
- 7.2c: A 3rd-inversion dominant 7th MUST resolve down by step to a 1st-inversion tonic chord.

Regarding the supertonic-seventh, the following precept applies:

- 8: The supertonic-7th chord MUST resolve to a (D)ominant-class chord, OR a 2nd-inversion tonic triad.

Regarding harmonic rhythm, the following precepts apply:

- 9a: It is preferable that the harmony change with each note of the exercise.
- 9b: It is strongly suggested that two adjacent chords sharing the same root should not be separated by a barline.

Regarding successions of inversions, the following precept applies:

- 10: Any bass progression of three or more notes DESCENDING BY STEP may be harmonized by 1st-inversion chords REGARDLESS of the resulting progression.

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Regarding specifically the mediant chord:

- 10.1: A root-position mediant chord **MUST** progress to a sub-dominant, or root-position submediant triad.

Regarding passing six-four chords, the following precept applies:

- 11a: A 2nd-inversion Tonic or Dominant chord **MAY** harmonize the middle note of a three note step-wise progression **IF** the outer two notes are harmonized by one root-position and one 1st-inversion form of the same chord.

Regarding neighbor six-four chords, the following precept applies:

- 11b: A 2nd-inversion Tonic or Submediant chord **MAY** harmonize the middle note of a three-note progression **IF** the outer-two bass notes are the same as that of the middle note **AND** the outer two notes are harmonized by the same root-position chord.

Regarding both six-four chords, the following precept applies:

- 11.1: All passing and neighbor six-four chords must appear on a beat weaker than the preceding beat.

Table 2. Middle-Level Control Heuristics.
(Rule numbers appear in '[..]')

"T" can harmonize a note **IF**
the next note is not harmonized **AND**
the next note is capable of supporting an acceptable chord
OR
it follows the rules for movement within a class [2.1d] **AND**
it does not repeat across a barline [9b] **AND**
if relevant, it follows the rules about cadential chords [1a-c]
OR
it follows the rules of (T)onic-class movement [2.1a] **AND**
it is **NOT** the same chord **AND**
if relevant, it follow the rules about cadential chords [1a-c] **AND**
if relevant, it is a proper preparation for a V⁷ [7.1a-b].

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"T⁶" can harmonize a note IF

the next note is not harmonized AND

the next note is capable of supporting an acceptable chord

OR

it follows the rules for movement within a class [2.1d] AND

it does not repeat across a barline [9b] AND

if relevant, it follows the rules about cadential chords [1a-c]

OR

it follows the rules of (T)onic-class movement [2.1a] AND

it is NOT the same chord AND

if a 1st inversion, it is preferred to resolve by step [4c] AND

if relevant, it follows the rules about cadential chords [1a-c]

OR

it follows the rules of (T)onic-class movement [2.1a] AND

succession_of_inv AND

if relevant, it follows the rules about cadential chords [1a-c]

OR

it follows the rules of (T)onic-class movement [2.1a] AND

it is NOT the same chord AND

if a 1st inversion, it is preferred to resolve by step [4c] AND

if relevant, it follows the rules about cadential chords [1a-c] AND

if relevant, it is a proper preparation for a V⁷ [7.1a-b].

"T^{6/4}" can harmonize a note IF

the next note is not harmonized AND

the next note is capable of supporting an acceptable chord AND

it must be part of a cadence [5d]

OR

it must resolve to a root-position dominant [5a] AND

the chord preceding it should be acceptable [5b] AND

it should be approached by step [5c] AND

it must resolve to a weaker beat [5.1a] AND

it must be part of a cadence [5d]

OR

it follows the rules for passing six-fours [11a] AND

it must be on a weak beat [11.1]

OR

it follows the rule for neighbor six-fours [11b] AND

it must be on a weak beat [11.1].

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"V" can harmonize a note IF
the next note is not harmonized AND
the next note is capable of supporting an acceptable chord
OR
it resolves to a V^7 [6a] AND
it does not repeat across a barline [9b]
OR
it follows the rules for movement within a class [2.1d] AND
it does not repeat across a barline [9b]
OR
it follows the rules for movement within a class [2.1d] AND
it is NOT the same chord
OR
it follows the rules for (D)-class movement [2.1c].

"V⁷" can harmonize a note IF
the next note is not harmonized AND
the next note is capable of supporting an acceptable chord.
OR
it progresses to the same chord AND
it does not resolve to a triad of the same class [6b] AND
if relevant, it is a proper preparation for a V^7 [7.1a-b] AND
it progresses to the same chord in inversion [4a] AND
it does not repeat across a barline [9b]
OR
it must resolve to a (T)-class chord [7a].

"V⁶" can harmonize a note IF
the next note is not harmonized AND
the next note is capable of supporting an acceptable chord
OR
it resolves to a V^7 [6a] AND
it does not repeat across a barline [9b]
OR
it progresses to the same chord AND
it shouldn't move to the same chord in root position [4b] AND
it does not repeat across a barline [9b]
OR
it follows the rules for movement within a class [2.1d] AND
it is NOT the same chord
OR

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it is part of a descending succession of inversions [10]

OR

if a 1st inversion, it is preferred to resolve by step [4c] AND
it follows the rules for (D)-class movement [2.1c].

"V^{6/4}" can harmonize a note IF

the next note is not harmonized AND

the next note is capable of supporting an acceptable chord

OR

it follows the rules for passing six-fours [11a] AND

it must be on a weak beat [11.1].

"V^{6/5}," "V^{4/3}," or "V^{4/2}" can harmonize a note IF

the next note is not harmonized AND

the next note is capable of supporting an acceptable chord

OR

if relevant, it is a proper preparation for a V⁷ [7.1a-b] AND

it resolves correctly [7.2a-c].

"VII⁰⁶" can harmonize a note IF

the next note is not harmonized AND

the next note is capable of supporting an acceptable chord

OR

it follows the rules for movement within a class [2.1d] AND

if relevant, it is a proper preparation for a V⁷ [7.1a-b]

OR

it is part of a descending succession of inversions [10]

OR

it follows the rules for (D)-class movement [2.1c] AND

if relevant, it is a proper preparation for a V⁷ [7.1a-b] AND

if a 1st inversion, it is preferred to resolve by step [4c].

"IV" or "II" can harmonize a note IF

the next note is not harmonized AND

the next note is capable of supporting an acceptable chord

OR

it progresses to the same chord AND

it progresses to the same chord in inversion [4a] AND

it does not repeat across a barline [9b] AND

if relevant, it follows the rules about cadential chords [1a-c]

OR

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it follows the rules for movement within a class [2.1d] AND
it is NOT the same chord AND
if relevant, it follows the rules about cadential chords [1a-c]
OR
it follows the rules of (S)ubdominant-class movement AND
if relevant, it follows the rules about cadential chords [1a-c] .

"TV⁶" or "II⁶" can harmonize a note IF
the next note is not harmonized AND
the next note is capable of supporting an acceptable chord
OR
it progresses to the same chord AND
if shouldn't move to the same chord in root position [4b] AND
it does not repeat across a barline [9b] AND
if relevant, it follows the rules about cadential chords [1a-c]
OR
it follows the rules for movement within a class [2.1d] AND
it is NOT the same chord AND
if relevant, it follows the rules about cadential chords [1a-c]
OR
if a 1st inversion, it is preferred to resolve by step [4c] AND
it is NOT the same chord AND
OR
it is part of a descending succession of inversions [10]
OR
it follows the rules of (S)ubdominant-class movement AND
if relevant, it follows the rules about cadential chords [1a-c] .

"TV^{6/4}" can harmonize a note IF
it follows the rules for neighbor six-fours [11b] AND
it must be on a weak beat [11.1].

{"II" same as "IV"}

"II⁷" can harmonize a note IF
it follows the rules for movement within a class [2.1d] AND
it does not repeat across a barline [9b]
OR
it does not resolve to a triad of the same class [6b] AND
it does not repeat across a barline [9b]
OR
it resolves to a (D)-class chord [8].

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{**"II⁶"** same as **"IV⁶"**}

"II^{6/5}" can harmonize a note IF

it follows the rules for movement within a class [2.1d] AND

it does not repeat across a barline [9b]

OR

it does not resolve to a triad of the same class [6b] AND

it does not repeat across a barline [9b]

OR

if a 1st inversion, it is preferred to resolve by step [4c] AND

it is NOT the same chord AND

it resolves to a (D)-class chord [8]

OR

it resolves to a (D)-class chord [8]

OR

it is part of a descending succession of inversions [10].

"VI" can harmonize a note IF

it follows the rules of (S)ubdominant-class movement AND

it cannot be penultimate to a tonic final [1b] AND

if the final chord, it must function as a deceptive cadence [1c] AND

if relevant, it follows the rules about cadential chords [1a-c]

OR

it follows the rules of (T)onic-class movement [2.1a] AND

it cannot be penultimate to a tonic final [1b] AND

if the final chord, it must function as a deceptive cadence [1c] AND

if relevant, it follows the rules about cadential chords [1a-c].

"VI⁶" can harmonize a note IF

it is part of a descending succession of inversions [10].

"III" can harmonize a note IF

it must progress to a subdominant or submediant [10.1].

"III⁶" can harmonize a note IF

it is part of a descending succession of inversions [10].

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Table 3. Highest-Level Control Heuristics

ATTEMPT TO ASSERT A CHORD AT A GIVEN POSITION IF

the note is in the LAST position of the exercise AND /* last position */
the chord choice harmonizes the given note AND
the previous chord is not NULL AND
reverse loop and try position POS-1 ==>
[SUCCESS!]

OR

the note is in the LAST position of the exercise AND
the chord choice harmonizes the given note AND
the previous chord is NULL AND
check for allowable cadence choices ==>
[SUCCESS!]

OR

the note is in the FIRST position of the exercise AND /* first position */
check all forward-referenced chord pairs ==>
[SUCCESS!]

OR

the note is in the MIDDLE of the exercise AND /* middle positions */
the previous chord is not NULL AND
check all forward-referenced chord pairs AND
reverse loop and check chord pair(s) position POS-1, etc. ==>
[SUCCESS!]

OR

the note is in the MIDDLE of the exercise AND
the previous chord is NULL AND
check all forward-referenced chord pairs ==>
[SUCCESS!]

OR

[FAILURE!]

/* failure */

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NOTES

¹For a more comprehensive overview of the program refer to the article "Harmony Coach: An Exploration of Microcomputer-Based Intelligent Tutoring Systems in Music," *Journal of Computer-based Instruction* 18 (Spring 1991).

²As an aside, it is unfortunate that these are the elements too often taught to beginning harmony students in a manner that simply informs them of the *what*, but due to lack of instructional time, are not always followed up with the *how* and *why* of the application of that information. The primary role of the *HARMONY COACH* is to do just that—namely to coach the application of a previously learned skill in such a manner as to imitate the subtle help an observant teacher might give a student in a focused individual tutoring session.

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