Down the Musical Garden Path: Shared Syntactic Processing in Music and Language

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Abstract

This paper further investigates shared resources between music and language processing, particularly the idea proposed by Slevc and Okada (2015) that the resources involve syntactic ambiguity resolution. Ninety-two participants completed a self-paced reading task with syntactic garden path sentences, which contain points of ambiguity and disambiguation, as well as sentences with double-embedded clauses, which are syntactically difficult to process but do not contain the type of ambiguity found in the garden path construction. These sentences were presented with chord progressions that were either in-key or contained one harmonically unexpected chord. Participants also completed the Profile of Music Perception Skills (PROMS) and were given a musicianship score. There was numerical evidence of an interaction between these harmonically unexpected chords and the garden paths, but not with the double-embedded sentences, although these were not statistically supported. Additionally, there were indications of an interaction between musicianship score and harmonic expectancy in the chords, which leaves some unanswered questions about how musicianship affects music and language processing.

Keywords: music, syntax, PROMS, SSIRH

Down the Musical Garden Path: Shared Syntactic Processing in Music and Language

Music cognition is at the forefront of a fascinating, rapidly developing field of psychology that is only beginning to be understood. The field is split up into two major sub-divisions of topics: emotional processing and cognitive processing. The emotional processing side is interested in how different types and genres of music can affect mood, personality, etc. (Poon and Schutz, 2015; Colver and El-Alayli, 2016; Garrido, Baker, Davidson, Moore, & Wasserman, 2015). The cognitive field, however, is more interested in how music is processed in the brain. There are many ways to measure musical cognitive processing, including pupillometry (Gingras, Marin, Puig-Waldmüller, & Fitch, 2015), eye-tracking (Ahken, Comeau, Hébert, & Balasubramaniam, 2012), and neuroimaging (Maess, Koelsch, Gunter, & Friederici, 2001).

There are many similarities between music and language, both in general properties and more specific structural aspects. Both language and music are unique to humans, and there is local variance of both across cultures (Jackendoff, 2009). Both domains have prosodic features; in language, this refers to things like intonation, emphasis, and phrasing. In music, however, these features include tempo, rhythm, and accents. Additionally, both music and language contain syntax, or a set of rules dictating how smaller units relate to each other to form a larger, more cohesive unit or phrase. Both domain have a syntax comprised of rules governing dominance relationships. In language, each phrase has a word that acts as the "head" and determines the syntactic category of the phrase (Figure 1). The rules that govern sentence structure (i.e. A sentence contains at least a noun phrase and a verb phrase; The subject and the verb must agree in terms of number) create expectations for what is coming next while reading through a sentence. Music also has a syntax concerned with these dominance relationships, which is regarding the importance of a note or chord in a phrase, usually the tonic or root (Figure

2). Typically, a phrase will begin, end, and/or center around the tonic note of the key. This also refers to the relationships of different chords in an established key, determined by a key signature (Figure 3). Only certain chords are in an established key. As in language, these rules also create expectations for the next note or chord in a piece, whether that is expecting the tonic chord at the end of a phrase or expecting all chords to be in the established key.

From these rules comes a set of expectations when listening to a piece of music or reading through a sentence. Moving through each, the listener or reader is constantly integrating the next chord or word into the mental framework of what the larger progression or sentence should be. This is especially clear when the expectancy is violated, as demonstrated in garden path sentences, explained below. From this comes Patel's Shared Syntactic Integration Resource Hypothesis (SSIRH) (2003), which postulates that while there are separate representations of music and language, there is some overlap in neural area and processes related to integration between music and language syntax. Patel's view can be contrasted with the claim that music and language both make use of domain-general cognitive control resources (Slevc & Okada, 2015). Distinguishing between these theoretical views entails testing two key questions: Is the processing overlap specific to syntactic processing? Is the overlap present for both syntactic and semantic processing when certain kinds of cognitive control are required? As described below, the initial evidence seemed to favor syntactic specificity (Slevc, Rosenberg, & Patel, 2009), but additional data made the cognitive control account more plausible (Perruchet & Poulin-Charronnat, 2012).

Pinpointing syntactic integration as the shared resources allows for a deeper investigation into those resources, such as whether these resources are limited to syntactic integration, or if they can be generalized to semantic processing and integration. A commonly used linguistic

structure in these types of experiments is the garden path sentence. A garden path sentence is a grammatically correct, but temporarily ambiguous, sentence that leads the reader through the sentence to a disambiguating word or phrase that changes the hierarchical organization of the sentence. “The horse raced past the barn fell to the ground” is a common example of a garden path sentence. In this case, “fell” is the disambiguating word, indicating that the sentence actually means that the horse that was raced by someone past the barn fell down. Since the disambiguating word is unexpected and requires the reader to reevaluate the sentence, the reading time is longer on the disambiguating word (in this case, “fell”); this is called the garden path effect.

Slevc et al. (2009) used garden path sentences to examine shared syntactic processing resources between music and language and to test the SSIRH. In Experiment 1, participants read sentences that either manipulated syntactic expectancy with a reduced relative clause which created a syntactic garden path (i.e. The attorney advised (that) the defendant was likely to commit more crimes), or manipulated semantic violation (i.e. The boss warned the mailman to watch for angry dogs (pigs) when delivering the mail). The sentences were paired with chord progressions that were either all in-key or contained one harmonically unexpected chord, which is analogous to a syntactically unexpected word. Participants saw each sentence presented phrase-by-phrase, and each phrase was paired with a chord; the out-of-key chord in those conditions was paired with the disambiguating word in the sentence. Harmonic expectancy interacted only with the garden path sentences. When both harmonic expectancy and syntactic expectancy were violated, the garden path effect was larger. However, the semantic violation effect was not larger when combined with a harmonic expectancy violation. The SSIRH predicts this pattern because the cognitive resources required for garden path recovery should be less

available when harmonic expectancy is also violated; both garden path recovery and harmonic violations place extra demands on the same syntactic processing resources. Slevc and colleagues further explored the semantic expectancy in Experiment 2, where they created a semantic musical manipulation where, instead of an out-of-key chord, there was one chord with a different timbre, or sound quality (the sound of a piano versus a pipe organ). The unexpected timbre is analogous to an unexpected word. When paired with the same linguistic stimuli from Experiment 1 using the same experimental design, they found that timbral expectancy had no interaction with garden path and semantic expectancy effects. The combined findings of Experiment 1 and Experiment 2 indicate that there is overlap in only syntactic processing resources, not semantic, between music and language.

While Slevc's 2009 findings fit with the predictions of the SSIRH, other studies have presented dissenting conclusions. Perruchet and Poulin-Charronnat (2012) used the musical syntactic manipulations from Slevc's study and paired those with semantic garden path sentences (i.e. The old man went to the (river) bank to withdraw his net, which was empty) instead of the previously used semantic violations. Perruchet and Poulin-Charronnat found a very similar interaction to that of Slevc et al—that there was a greater garden path effect when paired with harmonically unexpected chords, but no such interaction with semantic (timbral) manipulations, indicating that earlier findings are not restricted to syntactic processing, but may be generalized to the garden path construction itself.

Slevc and Okada (2015) used these findings to expand upon the SSIRH: they postulated that the shared resources are indeed not specific to syntax, but they involve specific aspects of cognitive control involved in the revision of a previous interpretation due to ambiguity. At the point of disambiguation, a conflict must be resolved; the current interpretation must be inhibited

while an alternative interpretation is adopted. Conflict resolution relies upon domain-general cognitive control resources. Perruchet and Poulin-Charronnat also found an interaction with semantic garden path sentences because the garden path structure requires ambiguity resolution. In order to test Slevc and Okada's (2015) idea, this experiment was designed to distinguish between conflict/ambiguity resolution and syntactic difficulty that was unrelated to ambiguity resolution. Thus, we compared garden path sentences with doubly-nested relative clause sentences. The difficulty in processing for doubly-nested sentences does not come from an ambiguity in the sentence, but from an effect often referred to as "processing overload" (Gibson, 1998) because such sentences set up three subject noun phrases in sequence, followed by three verb phrases. As each verb is encountered, it must be matched with its subject and (if applicable) direct object. An example sentence is, "The water that the man that the girl saw carried spilled on the ground." While garden path sentences have a clear disambiguating word, these sentences with doubly-nested clauses do not have such a clear region of difficulty. However, readers tend to have the most trouble with the three consecutive verbs (in the above sentence: "saw carried spilled") and therefore the overall meaning of the sentence.

Another perspective through which to view music and language, one which was looked at but not analyzed by Slevc et al. in 2009, is musicianship. Many studies have investigated the brain of a musician; there is evidence for differences in left hemispheric activation in musicians while listening to piano music (Baumann et al, 2007), as well as increased Broca's area volume (Sluming, Brooks, Howard, Downes, & Roberts, 2007). However, these studies, as well as other experiments focusing on music cognition, often categorize participants into either "musicians" or "non-musicians" based on number of years of formal training or experience (Gingras et al., 2015; Fiveash & Pammer, 2014; Hutka, Bidelman, & Moreno, 2015). This method of classification

excludes musicians who may be trained in nonclassical, non-Western genres, as well as those who are self-taught. Additionally, as many of the above studies consider a certain number of years of formal training to be the separation between the two groups, "non-musicians" tend to have some minimal training or experience (Chin & Rickard, 2012). The ideal measure of musicianship is one based solely on musical aptitude, not training or experience, with the score placed on a continuous gradient scale rather than categorized into "musician" or "non-musician."

There is also evidence to suggest that musicians are more sensitive or attuned to mistakes or expectancy violations in music. In a study done by Patston and Tippett (2011), musicians completing a language comprehension task performed more poorly not only when there was music playing in the background, but even more so when there were mistakes in the background music. As these musicians tend to be more affected by mistakes in the music, they should be more affected by the unexpected out-of-key chords in this study

This study aims to gain further insight into Slevc and Okada's 2015 hypothesis that shared processing lies in cognitive reinterpretation during ambiguity resolution. If they are correct, manipulations in harmonic expectancy should exacerbate the garden path effect, but they should not interact with difficulty effects while reading sentences with double-embedded clauses. Additionally, there should be a positive correlation between musicianship levels and this increased garden path effect.

Materials and Methods

Participants

92 University of Michigan undergraduate students participated in this study, either receiving course credit in exchange or as a volunteer. Participants ranged in age from 18-27 (M = 19.03), with 45 male and 47 female. 46% play or have played an instrument, and 43% reported

themselves as able to read music. When given a 5-point Likert scale (1 = ”Non-musician”, 2 = ”Music-loving non-musician”, 3 = ”Amateur musician”, 4 = ”Proficient musician”, 5 = ”Professional musician”), 62% identified themselves as either a non-musician or a music-loving non-musician, 28% as amateur musician, and 10% as proficient.

Stimuli

Sentences. Half of the critical sentences were syntactic garden path (GP) sentences with object relative clauses. The GP control condition differed only by the addition of “that/who was” (see Table 1). The critical region of the GP and GP-control sentences was the “was” after the relative clause, and the regions before and after the critical region remained the same across conditions. GP sentences lengths varied across items. Half of the critical sentences were sentences with doubly-embedded relative clauses (DE), with the third verb acting as the critical region. The DE control condition separated out the embedded relative clauses using the same verb and noun phrases, keeping the same number of phrases across conditions, as well as keeping the critical region and the following phrase the same. Filler sentences contained neither garden path construction nor doubly-embedded clauses, and varied in length.

Chords. Chord sequences were arranged using MuseScore 2 arranging software. The chords in the progression were either all in the key or C (in-key condition), or one chord was not in key (out-of-key condition). The first and last chord of each progression was in C major, and in the out-of-key condition, the critical chord was the tonic chord of keys 3-5 steps away from C major on the circle of fifths (Figure 3). When paired with a sentence, the out-of-key chord corresponded to the critical region in the sentence.

Methods

Each participant saw every critical sentence in either its experimental or control condition, paired with either an in-key or out-of-key chord progression. Each participant saw 32 GP or GP-con sentences, 32 DE or DE-con sentences, and 80 fillers. These combinations were randomly spread across 4 lists; each list contained 16 GP, 16 GP_con, 16 DE, 16 DE_con, and 80 filler sentences. Participants also saw 6 practice trials before beginning the experiment. The experiment was created using PsychoPy.

Procedure

After consenting, participants were given the abridged version of the Profile of Music Perception Skills (PROMS) (2012). The PROMS-S began with a short demographic and musical background survey, followed by 3 subtests in melody recognition, rhythm recognition, and tuning. Based on their performance on this measure, participants were assigned a musicianship score, the highest possible score being 53. After completing the PROMS, participants were given the self-paced reading task. During the reading task, sentences appeared in 1-3 word phrases in the center of the screen accompanied by each chord of the corresponding chord progression. Participants progressed through the sentence by pressing the spacebar. Each trial was followed

by a sensibility question, asking whether or not the participant understood the sentence. The full experiment was given on a Mac desktop computer, and it took 40 minutes to complete.

Results

The maximum score achievable on the given PROMS measure was 53. The scores formed a normal distribution (M = 28.130, SD = 7.711), as seen in Figure 4.

To remove outliers from the data, reading times greater than the experiment mean reading time plus 2.5 standard deviations were replaced with that number. The areas of interest were the phrase preceding the critical region, the critical region, and the phrase following the critical region. Average reading times across conditions for these three regions, as well as the different chord conditions, can be found in Table 2. In the GP condition at the critical region, the difference in reading times between the GP and GP-con sentences demonstrated the expected garden path effect (Figure 5). Additionally, the size of the garden path effect at the critical region was larger for the out-of-key condition (228 ms) than for the in-key condition (164 ms). Overall, the DE and DE-con sentences followed mostly the same pattern, although reading times for DE sentences were overall slower, which was expected. In both the DE and DE-con sentences, reading times stayed relatively consistent from the preceding to the critical regions across conditions, then saw a large increase at the following region, likely due to a last word effect (Figure 6). The following statistical analyses were conducted to verify these findings.

The reading times in the preceding, critical, and following regions were analyzed separately using a linear mixed effects model, LMER, with the lme4 package in R (Bates, Maechler, Bolker, & Walker, 2013) (Figure 7). Sentence number (item) and participant (subj) were both analyzed as crossed random factors, which is common in psycholinguistics and allows for lower Type-1 error rates (Clark, 1973). Fixed effects were set as trial number

(TrialNum.scaled), sentence type, meaning whether a sentence was DE or GP (degp), whether the sentence was critical or a control (cc), musicianship score (FinalScore.scaled), and key (key). Categorical variables (cc, key, degp) were centered. The model also looked at interactions between FinalScore.scaled, degp, cc, and key.

Several significant main effects were found: Trial number (b = -66.320, $t(74) = -5.890$, $p < .001$), indicating that participants were reading through each sentence more quickly as they moved through the experiment; sentence type (b = 100.596, $t(51) = 5.419$, $p < .001$); and critical-versus-control (b = 126.364, $t(30) = 11.776$, $p < .001$). There were main effects of key (b = 18.164, $t(2609) = 1.839$, $p = .066$) and musicianship score (b = 44.740, $t(92) = 1.809$, $p = .074$) that were borderline significant. There were also significant interactions between sentence type and critical-versus-control (b = 91.807, $t(5670) = 4.969$, $p < .001$), critical-versus-control and musicianship score (b = 11.288, $t(89) = 0.834$, $p < .01$), and three-way interactions between sentence type, critical-versus-control, and key (b = 76.933, $t(2864) = 1.963$, $p < .05$) and critical-versus-control, key, and musicianship score (b = -41.089, $t(5701) = -2.222$, $p < .05$).

To delve more deeply into the interaction between critical-versus-control and key, the same model was run twice more without the sentence type variable, once for only GP and once for only DE sentences. For GP sentences, there were significant main effects of critical-versus-control (b = 173.710, $t(31.60) = 8.357$, $p < .001$) and key (b = 34.61, $t(2708.20) = 2.514$, $p < .05$), and a borderline significant main effect of musicianship score (b = 50.450, $t(92) = 1.735$, $p = .086$). For the DE sentences, there was also a significant main effect of critical-versus-control (b = 8.249, $t(31.3) = 5.267$, $p < .001$), as well as a borderline significant effect of score (b = 38.423, $t(92.10) = 1.735$, $p = .086$). Neither model showed a significant interaction between critical-versus-control and key.

Discussion

As predicted by the SSIRH, there was a slightly increased garden path effect at the critical region when paired with an out-of-key chord shown in the reading times, but it was not verified by statistical analysis. When split into double embedded and garden path sentences, neither showed an interaction between critical versus control and key, meaning that although the reading time data hinted at the exacerbated garden path effect of out-of-key chords, it was not confirmed statistically.

The musicianship score was a borderline significant interaction with key and control versus critical sentences. However, there may have been a confidence effect stemming from the way the PROMS test was scored; participants responded to each question on a 3-point Likert scale (1 = Definitely different, 2 = Probably different, 3 = I don't know, 4 = Probably same, 5 = Definitely same), where a "definitely" on the correct side was worth 2 points, a "probably" was worth 1 point, and the other three answers were worth 0 points. Looking at the results, there were strong correlations between musicianship score and the self-assigned musicianship rating ($r(90) = 0.552$, $p < 0.05$) and between musicianship score and whether they play an instrument ($r(90) = 0.559$, $p < 0.05$), indicating that those who had musical background were more likely to choose "definitely" over "probably." This could be ameliorated in the future by using a 3-point scale instead (1 = Different, 2 = I don't know, 3 = Same).

Another confounding factor may have been how the participant listened to the music. Although instructed to focus on the sentences, some participants reported to the experimenters that they moved through the sentences so that the chords formed an even beat (i.e. giving the same time to each chord regardless of the words on the screen).

Additionally, this study did not control for distraction in the musical stimuli. In their study, Fiveash and Pammer (2014) had an additional condition using the semantic manipulation from the Slevc (2009) study with a timbral inconsistency, but they used it as a control to rule out the possibility that slower reading times could be due not to processing difficulties, but to surprise or distraction at the unexpected chord. This study's lack of such a control condition could explain the unexpected results with main effects and interactions involving key; participants may have reacted to the out-of-key condition independently of the linguistic stimuli.

The interesting hint at an interaction between musicianship and key should be further investigated in this context, perhaps with a different musicianship measure or the PROMS with a 3-point scale. Further studies may also consider recruiting participants from musical communities, such as professional orchestras or music schools, in order to target a more specialized pool of participants.

These findings also provide some insight into the question of domain specificity versus generality in music and language. One of the key tenets of the SSIRH, which was also upheld by Slevc and Okada, is that representations of music and language are domain specific and separable from one another; it is only the cognitive control aspects of revision and reinterpretation that overlap and are shared between the domains.

References

Ahken, S., Comeau, G., Hébert, S., & Balasubramaniam, R. (2012). Eye movement patterns during the processing of musical and syntactic incongruities. *Psychomusicology: Music, Mind, & Brain 22*(1), 18-25. http://dx.doi.org/10.1037/a0026751

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48. doi:10.18637/jss.v067.i01

Baumann, S., Koeneke, S., Schmidt, C. F., Meyer, M., Lutz, K., & Jancke, L. (2007). A network for audio-motor coordination in skilled pianists and non-musicians. *Brain Research*, 1161, 65–78. http://dx.doi.org/10.1016/j.brainres.2007.05.045

Chin, T., & Rickard, N. (2012). Reconcenptualizing 'musicianship': Music performance and training through to music reception and engagement. In Rickard, N. S., McFerran, K. (Ed.), *Lifelong engagement with music: Benefits for mental health and well-being* (pp. 161-180) Nova.

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. Journal of verbal learning and verbal behavior, 12(4), 335-359.

Colver, M. C., & El-Alayli, A. (2016). Getting aesthetic chills from music: The connection between openness to experience and frisson. *Psychology of Music, 44*(3), 413-427. doi:10.1177/0305735615572358

Fiveash, A., & Pammer, K. (2014). Music and language: Do they draw on similar syntactic working memory resources? *Psychology of Music, 42*(2), 190-209. doi:10.1177/0305735612463949

Garrido, S., Baker, F. A., Davidson, J. W., Moore, G., & Wasserman, S. (2015). Music and trauma: The relationship between music, personality, and coping style. *Frontiers in Psychology, 6.* doi:10.3389/fpsyg.2015.00977

Gibson, E. (1998). Linguistic complexity: Locailty of syntactic dependencies. *Cognition, 68*, 1-76. http://dx.doi.org/10.1016/S0010-0277(98)00034-1

Gingras, B., Marin, M. M., Puig-Waldmüller, E., and Fitch, W. T. (2015). The eye is listening: Music-induced arousal and individual differences predict pupillary responses. *Frontiers in Human Neuroscience.* 9:619. doi:10.3389/fnhum.2015.00619

Hutka, S., Bidelman, G. M., & Moreno, S. (2015). Pitch expertise is not created equal: Cross-domain effects of musicianship and tone language experience on neural and behavioural discrimination of speech and music. *Neuropsychologia 71*, 52-63. http://dx.doi.org/10.1016/j.neuropsychologia.2015.03.019

Jackendoff, R. (2009). Parallels and Nonparallels between Language and Music. *Music Perception: An Interdisciplinary Journal,26*(3), 195-204. doi:10.1525/mp.2009.26.3.195

Koelsch, S., Rohrmeier, M., Torrecuso, R., & Jentschke, S. (2013). Processing of hierarchical syntactic structure in music. *PNAS Proceedings Of The National Academy Of Sciences Of The United States Of American, 110*(38). 15443-15448. doi:10.1073/pnas.1300272110

Law, L. & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the Profile of Music Perception Skills. *PLoS ONE 7*(12): e52508.

Law, L.C., & Zentner, M. (2012). Profile of Music Perception Skills. *Psyctests,* doi:10.1037/t26932-000

Maess, B., Koelsch, S., Gunter, T. C., & Friederici, A. D. (2001). Musical syntax is processed in Broca's area: an MEG study. *Nature Neuroscience, 4*(5), 540-545. doi:10.1038/87502

Patel, A. D. (2003). Language, music, syntax and the brain. *Nature Neuroscience, 6*(7), 674-681. doi:10.1038/nn1082

Patston, L. L., & Tippett, L. J. (2011). The Effect of Background Music on Cognitive Performance in Musicians and Nonmusicians. *Music Perception: An Interdisciplinary Journal*,*29*(2), 173-183. doi:10.1525/mp.2011.29.2.173

Perruchet, P., & Poulin-Charronnat, B. (2013). Challenging prior evidence for a shared syntactic processor for language and music. *Psychonomic Bulletin & Review, 20*(2), 310-317. doi:10.3758/s13423-012-0344-5

Poon, M., & Schutz, M. (2015). Cueing musical emotions: An empirical analysis of 24-piece sets by Bach and Chopin documents parallels with emotional speech. *Frontiers in Psychology.* 6:1419. doi: 10.3389/fpsyg.2015.01419

Slevc, L. R., & Okada, B. M. (2015). Processing structure in language and music: A case for shared reliance on cognitive control. *Psychonomic Bulletin & Review, 22*(3), 637-652. doi:10.3758/s13423-014-0712-4

Slevc, L. R., Rosenberg, J. C., & Patel, A. D. (2009). Making psycholinguistics musical: Self-paced reading time evidence for shared processing of linguistic and musical syntax. *Psychonomic Bulletin & Review, 16*(2), 374-381. doi:10.3758/16.2.374

Sluming, V., Brooks, J., Howard, M., Downes, J. J., & Roberts, N. (2007). Broca's Area Supports Enhanced Visuospatial Cognition in Orchestral Musicians. *Journal of Neuroscience*, 27, 3799–3806. doi: https://doi.org/10.1523/JNEUROSCI.0147-07.2007

Tables

Table 1

Critical Sentences

Region							Preceding	**Critical**	Following
GP					The shopkeeper	sent	the flowers	**was**	pleased.
GP_con				The shopkeeper	who was	sent	the flowers	**was**	pleased.
DE	The dogs	that	the story	that	he	told	described	**performed**	tricks.
DE_con	He	told	a story	that	described	dogs	that	**performed**	tricks.

Table 1: Layout of sentences in self-paced reading tasks. Sentences differed in length, but the critical region (in bold) was adjusted to be the same region position during analysis. The types of sentences are garden path (GP), garden path control (GP_con), double embedded clauses (DE), and double embedded clause controls (DE_con).

Table 2

Mean Reading Times of Critical and Surrounding Regions

	Preceding Region	Critical Region	Following Region
DE			
In-Key	724	722	1225
Out-of-Key	676	687	1256
DE_con			
In-Key	613	595	1343
Out-of-Key	626	612	1379
GP			
In-Key	727	829	982
Out-of-Key	780	882	803
GP_con			
In-Key	769	665	836
Out-of-Key	773	654	761

Table 2: Mean reading times (in milliseconds) across language and musical conditions.

Figures

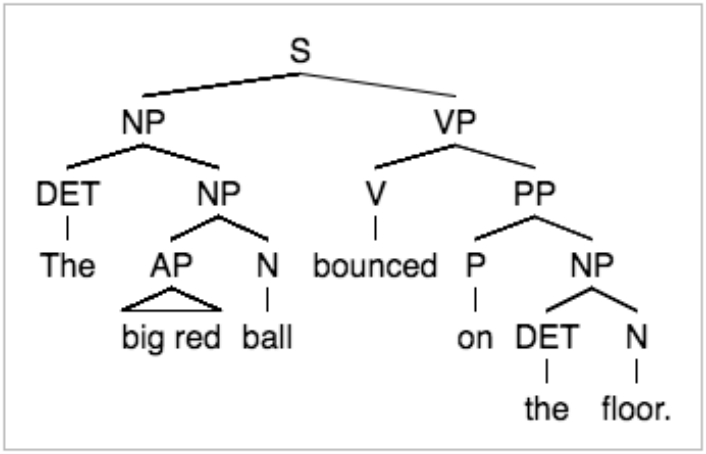


Figure 1. A syntactic tree for the sentence, "The big red ball bounced on the floor." As dictated by rules of syntax, the sentence is made up of a noun phrase (NP) and a verb phrase (VP), each of which is determined by its respective head. In the NP, the head is "ball," and in the VP, the head is "bounced."

Figure 2. A time span reduction tree of the children's song "Hush Little Baby." Longer branches indicate more important or dominant notes in the phrase. The song is in the key of F major, and it ends on an F note, which is the tonic of the key. From Patel (2003).

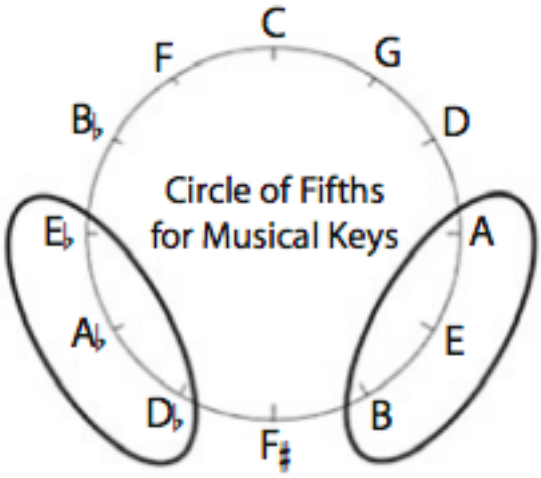


Figure 3. The Circle of Fifths for musical keys. The circle serves as a graphic representation of the relationships between all 12 semitones and their respective key signatures. In-key chords were all in the key of C, and out-of-key chords were 3-5 steps away from C on the circle, indicated by the ovals. Adopted from Slevc et al. (2009).

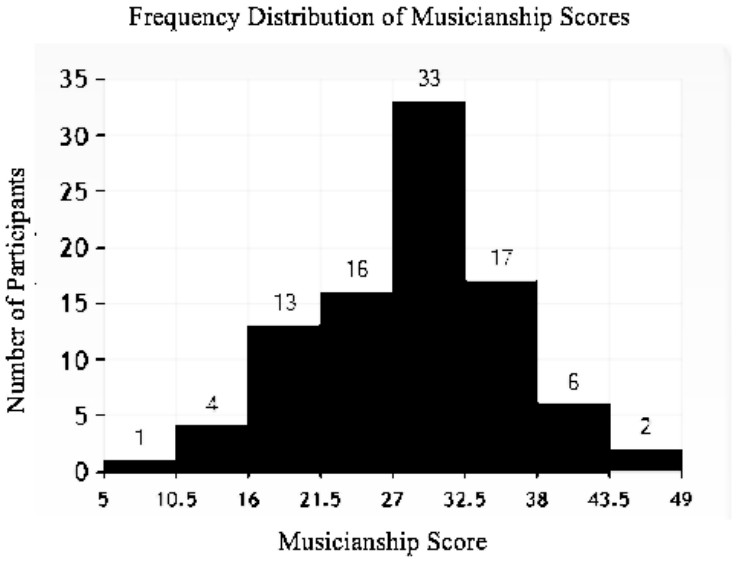


Figure 4. The distribution of finals scores on the PROMS measure. The maximum score achievable was 53.

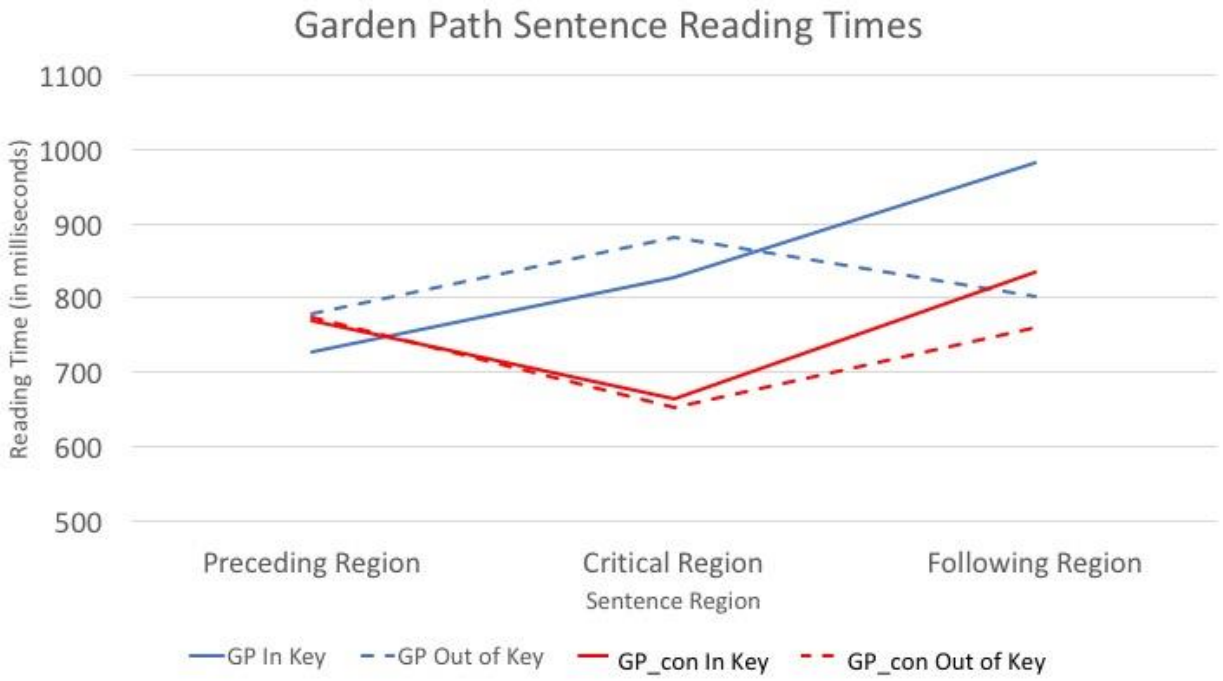


Figure 5. Average reading times (in milliseconds) for garden path and garden path control sentences.

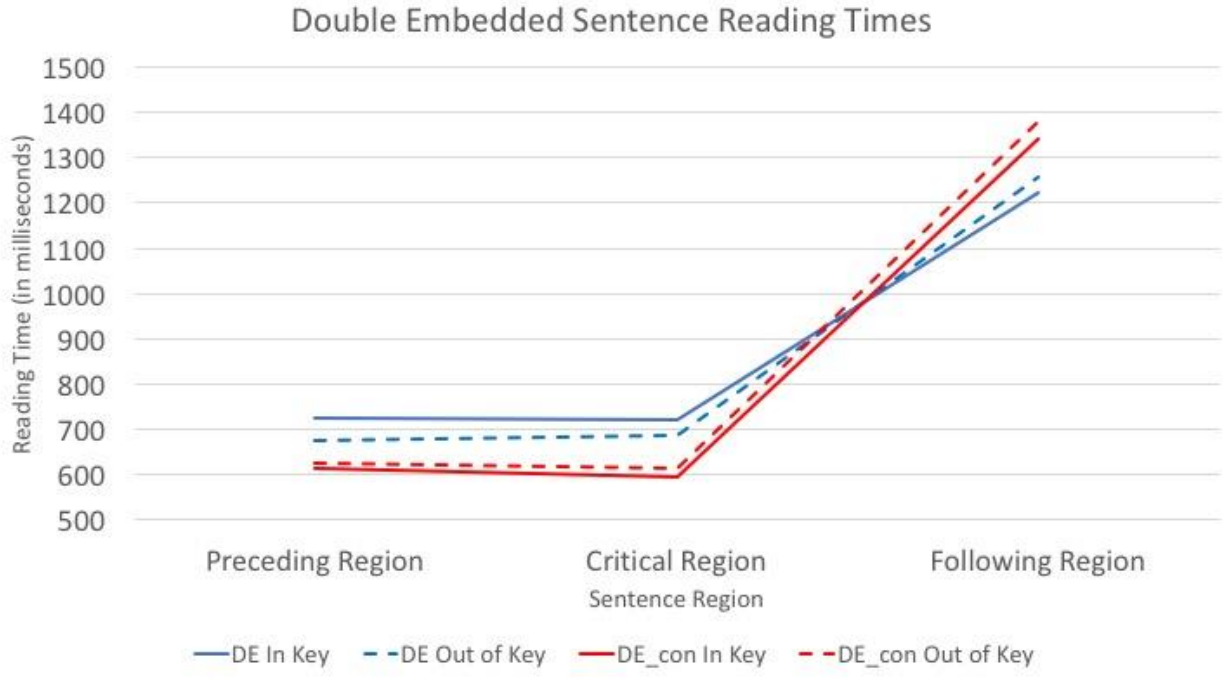


Figure 6. Average reading times (in milliseconds) for double embedded and double embedded control sentences.

```
criticalRegion <- lmer(SenTimes ~ TrialNum.scaled +
                         degp*cc*key*FinalScore.scaled +
                         (degp +
                            cc
                          || item) +
                         (TrialNum.scaled +
                            degp
                          || subj),
                       data = d[d$WordPos == 7,], verbose = T, REML = F)
```

Figure 7. The linear mixed-effect model used to analyze the reading time data. The model included sentence number (item) and participant number (subj) as crossed random factors, and trial number(TrialNum.scaled), sentence type (degp), musicianship score (FinalScore.scaled), whether the sentence was critical or control (cc), and key (key) as fixed effects.

Appendix A

Sentences are separated into phrases by "/" marks. Each segment was viewed on the screen individually as the participants moved through the experiment.

Garden Path and Controls

1. The shopkeeper/(who was)/sent/the flowers/was/pleased.
2. The pony/(that was)/raced/down the road/was/very friendly.
3. The boy/(who was)/pushed/through the door/was/very scared.
4. The bicycle/(that was)/smashed/into a wall/had been/stolen/from its owner's garage.
5. The lioness/(that was)/hunted/throughout the night/was/pregnant/with cubs.
6. The motorcycle/(that was)/crashed/into a fire hydrant/was/expensive/to repair.
7. The wrestler/(that was)/elected/the team captain/was/extremely late/to the match.
8. The woman/(who was)/served/the steak/was/only working/for the summer.
9. The airplane/(that was)/coasted/to a safe landing/was/carrying/several Michigan students.
10. The car/(that was)/spun/across the icy road/was/a prop/for a movie.
11. The mailman/(who was)/delivered/junk mail/was/annoyed.
12. The prisoner/(who was)/snuck/out of prison/was/hidden/in a nearby warehouse.
13. The ruthless dictator/(who was)/provided/the weapons/was/hated/throughout the country.
14. The troops/(who were)/marched/to their tents/were/very tired.
15. The princess/(who was)/waltzed/across the floor/was/next in line/for the throne.
16. The tree/(that was)/snapped/in half/during the storm/was/blocking/the street.
17. The guard/(who was)/searched/inside the prison/was/hiding/cocaine/in his jacket.
18. The girl/(who was)/wanted/to read/was/very nervous.
19. The boat/(that was)/floated/down the river/was/found stuck/on the shore.
20. The lawyer/(who was)/cheated/during the trial/was/furious/at the judge.
21. The juror/(who was)/accused/in the courtroom/was/dismissed/from the trial.
22. The rebels/(who were)/battled/in the war/were/soundly defeated.
23. The scientist/(who was)/presented/the award/was/overwhelmed/with joy.
24. The excited fan/(who was)/moved/during the song/was/angry/at the bouncers.
25. The student/(who was)/docked/points/was/found cheating/on the exam.
26. The author/(who was)/referred/to her publisher/was/almost finished/with her second novel.
27. The advertisement/(that was)/rotated/on the billboard/was/colorful/and effective.
28. The apprentice/(who was)/trained/for many hours/was/exhausted/from woodworking.
29. The student/(who was)/asked/many questions/was/very happy/with his grade.
30. The superhero/(who was)/promised/the city's safety/was/injured/by the villain.
31. The thief/(who was)/handed/ the money/was/held/for questioning.
32. The travelers/(who were)/stopped/in the desert/were/nervous/to see/the police officer.

Double Embedded Sentences

1. The dogs/that/the story/that/he/told/described/performed/tricks.
2. Everything/that/the people/who/she/invited/wanted/was waiting/in their rooms.
3. The shells/that/the children/who/we/watched/collected/were piled/in the sand.

4. Sentences/that/students/who/I/teach/memorize/can be/quite short.
5. The water/that/the man/who/she/saw/carried/spilled/on the ground.
6. The administrator/who/the intern/who/she/supervised/had bothered/lost/the medical reports.
7. The information/that/the reporter/who/I/knew/discovered/worried/the senator.
8. The employee/who/the manager/who/I/liked/had hired/knocked over/his coffee.
9. The man/who/the cat/that/she/owned/scratched/ran/the ice cream shop.
10. The girl/who/the man/who/I/saw/kissed/left/this morning.
11. The woman/who/the/man/who/I/love/met/lives/in Barcelona.
12. The driftwood/that/the canoes/that/we/built/were made from/washed up/on the shore.
13. The canal/that/the engineer/who/you/trained/worked on/was built/in West Virginia.
14. The report/that/the cadet/who/he/detests/sent in/was/late.
15. The apples/that/the children/who he helped/picked/contained/worms.
16. The toy dragon/that/the puppeteer/who/I/love/works with/fell apart/after the show.
17. The joke/that/the boy/who/she/babysits/told/was not/funny.
18. The balloons/that/the clown/who/they/adored/gave out/improved/the party.
19. The horse/that/the woman/who/I/hated/rode/ran/in the derby.
20. The rat/that/the cat/that/I/chased/ate/lived/under the porch.
21. The milk/that/the cow/that/I/owned/gave/smelled/funny.
22. The game/that/the boys/who/I/met/invented/resembles/chess.
23. The cheese/that/the rats/that/I/saw/ate/was/rancid.
24. The policies/that/the students/who/I/teach/object to/pertain/to smoking.
25. The pictures/that/the photographer/who/I/met/took/turned out/very well.
26. The football player/who/the cheerleader/who/I/dated/met/broke/his wrist.
27. The planes/that/the sailors/who/we/attacked/feared/were/enemy bombers.
28. The actors/who/the writer/who/you/called/used/were/extremely talented.
29. The material/that/the designer/who/we/hired/required/was/green.
30. The letter/that/the secretary/who/I/hired/mailed/arrived/late.
31. The box/that/the man/who/she/knew/dropped/was/heavy.
32. The results/that/the scientist/who/they/appointed/found/were/surprising.

Double Embedded Control Sentences

1. He/told/the story/that/described/dogs/that/performed/tricks.
2. She/invited/the people/who/wanted/everything/that/was waiting/in their rooms.
3. We/watched/the children/who/collected/the shells/that/were piled/in the sand.
4. I/taught/the students/who/memorize/sentences/that/ can be/quite short.
5. She/saw/the man/who/carried/the water/that/spilled/ on the ground.
6. She/supervised/the intern/who/bothered/the administrator/who/lost/the medical reports.
7. I/knew/the reporter/who/discovered/the information/that/worried/the senator.
8. I/liked/the manager/who/hired/the employee/who/knocked over/his coffee.
9. She/owned/the cat/that/scratched/the man/who /ran/the ice cream shop.
10. I/saw/the man/who/kissed/the girl/who/left/this morning.
11. I/love/the man/who/met/the woman/who/lives/in Barcelona.
12. We/built/the canoes/that/were made from/driftwood/that/washed up/onto the shore.

13. You/trained/the engineer/who/worked on/the canal/that/was built/in West Virginia.
14. He/detests/the cadet/who/sent in/the report/that/was/late.
15. He/helped/ the children/who/picked/the apples/that/contained/worms.
16. I/love/the puppeteer/who/works with/the toy dragon/that/fell apart/after the show.
17. She/babysits/the boy/who/told/the joke/that/was not/funny.
18. They/adored/the clown/who/gave out/the balloons/that/improved/the party.
19. I/hated/the woman/who/rode/the horse/that/ran/in the derby.
20. I/chased/the cat/that/ate/the rat/that/lived/under the porch.
21. I/owned/the cow/that/gave/the milk/that/smelled/funny.
22. I/met/the boys/who/invented/a game/that/resembles/chess.
23. I/saw/the rats/that/ate/the cheese/that/was/rancid.
24. I/taught/the students/who/object to/the policies/that/pertain to/smoking.
25. I/met/the photographer/who/took/the pictures/that/turned out/very well.
26. I/dated/the football player/who/met/the cheerleader/who/broke/his wrist.
27. We/attacked/the sailors/who/feared/the planes/that/were/enemy bombers.
28. You/called/the writer/who/used/the actors/who/were/extremely talented.
29. We/hired/the designer/who/required/the material/that/was/green.
30. I/hired/the secretary/who/mailed/the letter/that/arrived/late.
31. She/knew/the man/who/dropped/the box/that/was/heavy.
32. They/appointed/the scientist/who/found/the results/that/were/surprising.

Filler Sentences

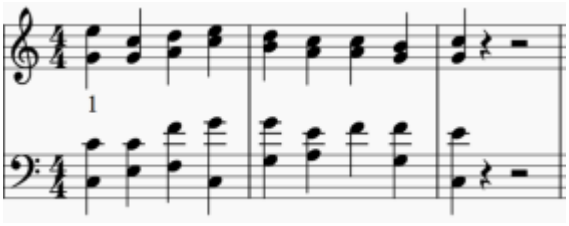
1. During/the exam,/the nervous student/wrote/hurriedly.
2. The new waitress/accidentally spilled/soup/all over/the grouchy customer.
3. The girl's cat/dragged/a bird/into her apartment/last night.
4. The college student/was upset/when/her credit card/was declined.
5. The clock/ticked/so loudly/that/it woke him up.
6. The barber/cut/the man's hair/much shorter/than expected.
7. The chef/tried/a new recipe/for grilled chicken/during the lunch rush.
8. The plumber/could not find/the problem/with the toilet/in the woman's apartment.
9. The student/watched/many tutorials/to help him/with his calculus homework.
10. The overworked barista/accidentally/gave/the woman/the wrong order.
11. The car/ran out/of gas/on the side/of the highway.
12. The amateur chef/burned/his finger/on the hot stove/this morning.
13. The students/cheered/when/the class bell/rang.
14. The spectators/gasped/as the runner/tripped/over the hurdle.
15. The dog/scared/the neighbors/with his angry barking/this morning.
16. At the circus,/fifteen clowns/managed/to it/into a small car.
17. The farmer/was/concerned/about/the lack of rain.
18. As/the parade/passed by/the school,/the kids/applauded.
19. While/the guard/watched/the television,/the hostage/escaped.
20. The singer/fell off/the stage/at his/sold-out concert/last week.
21. Our carpet/was ruined/when/the basement/flooded/during the storm.
22. The landlord/gave/the shiny keys/to the new tenants/when/they moved in.
23. The runner/ripped/a hole/in his tennis shoes/during/his first marathon.

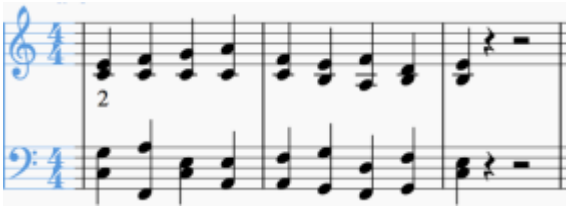
24. The tired bartender/poured/too much wine/into the glass/and spilled it/on the floor.
25. The masseuse/used/a variety/of new lotions/during her appointment/this morning.
26. The boy's friend/invited/him/to his house/to play/a new video game.
27. The feminist/proposed/a march/for women's rights/in the park/for next week.
28. The therapist/soothed/her patient/after/his/emotional divorce.
29. The weightlifter/lifted/his record weight/during/his most recent/competition.
30. The art student/painted/a portrait/of her brother/for her assignment/due tomorrow.
31. Everyone/watching the game/cringed/when/the football player/was injured.
32. As/the musician/practiced/the violin,/the baby/cried.
33. The bored spectators/jeered/when/the quarterback/fumbled/the ball.
34. After/her computer/was stolen,/the woman/called/the police.
35. The brown horse/grazed/with/the rest/of the herd/in the pasture.
36. The children/ate/chicken nuggets/for dinner/every day/for a week.
37. The man/rode his bike/through campus/on his way/to work/yesterday.
38. The doctor/prescribed/four/different/medications/to his patient.
39. The teenagers/were thrilled/when/school/was cancelled/due to weather.
40. The child/scraped his knee/when/he tripped/at the playground.
41. The guy/was/so hungry,/he ate/three cheeseburgers/and a milkshake.
42. The milk/became spoiled/when/the power/went out/after the hurricane.
43. The baseball player/cheered/when/his team/won/the championship.
44. The computer/froze/before/the document/was/saved.
45. The counselor/read/a story/to the camper/to help her/fall asleep.
46. The weather forecast/predicted/rain,/but/it was/a sunny day.
47. Everyone/in the theater/screamed/during/the scary movie/last night.
48. The team manager/turned away/and spat/after/the star player/struck out.
49. The man/relaxed/during the week/by/swimming laps/at the pool.
50. The history teacher/taught/a lesson/about/the civil war/on Friday.
51. The students/were/embarrassed/when/the librarian/shushed them.
52. The jury/debated/for three days/before/returning/a guilty verdict.
53. After/watching/the movie,/the critic/wrote/a negative review.
54. When/the monster/suddenly appeared,/the audience/shrieked.
55. While/the dog/chased/the ball,/the boy/talked/to his friends.
56. While/at the zoo/the kid/saw/a bunch/of monkeys/eating bananas.
57. The little boy/buckled/his seatbelt/after/his mother/yelled/at him.
58. After/the woman/finished/law school,/her father/gave her/a briefcase.
59. The man/took/his girlfriend/to a movie,/but she/did not like/the film.
60. The girl/got sunburned/very badly/while/swimming/in the lake/up north.
61. The crowd/booed/when/the comedian/told/a bad joke/during his set.
62. When/the man/tripped,/he dropped/the eggs/he/was carrying.
63. The student/was frustrated/when/her favorite song/got stuck/in her head/during the test.
64. When/the girl/realized/the last puzzle piece/was missing,/she/was upset.
65. The woman/cried/when/her boyfriend/proposed/to her/unexpectedly.
66. She/made/another appointment/with her doctor/when/she fell ill/again.
67. The baker/arrived/early/to the bakery/to start/a new batch/of cookies.
68. The athlete/visited/his doctor/when/his ankle/began to hurt/after the game.
69. Because/the taxi driver/made/a wrong turn,/the passenger/was late/to his meeting.

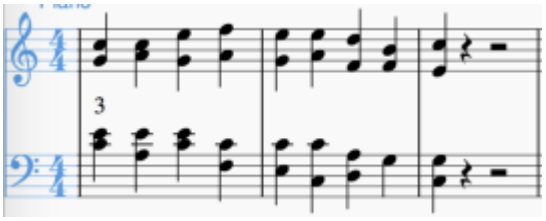
70. The sailor/frantically/pumped out/water/from his boat/during the rainstorm/yesterday.
71. When/the girl/met/her favorite celebrity,/she cried/and took/many pictures.
72. The old man/was/furious/when/the kids/ran/across his lawn.
73. The motivated student/studied/all night long,/but then/overslept/and missed/his test.
74. While/the construction worker/fixed/the house,/the family/went/on vacation/to Florida.
75. As/the professor/lectured/about/the boring topic,/the students/tried/to stay awake.
76. When/the student/graduated,/her family/gave her/money/and gift cards.
77. During/the football game,/my girlfriend/went shopping/and/bought/three pairs/of shoes.
78. After/the party/this weekend,/everyone/felt/terrible/at work/on Monday.
79. The students/in the dorm/were upset/when/the fire alarm/blared/early/this morning.
80. When/the cashier/handed/my change/to me,/I/dropped/the coins.

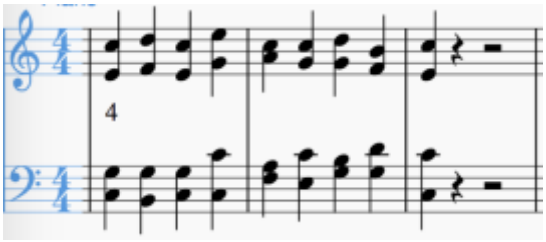
Appendix B

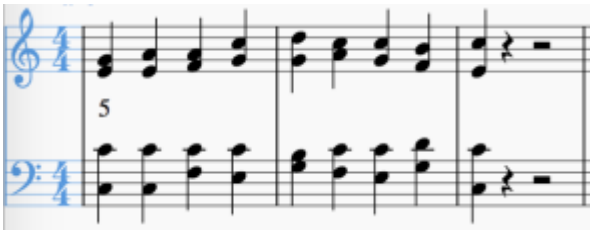
In-Key Chord Progressions

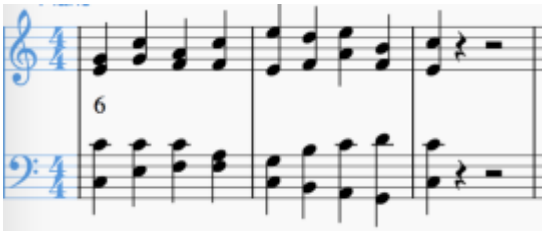
1. 

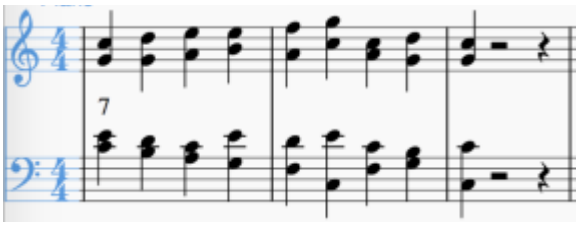
2. 

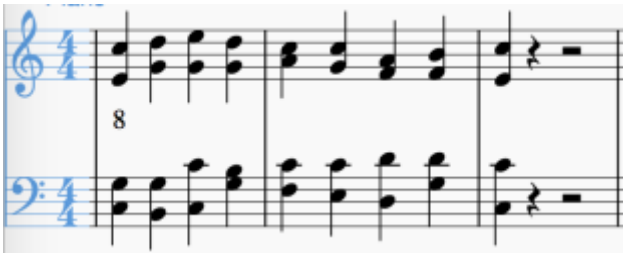
3. 

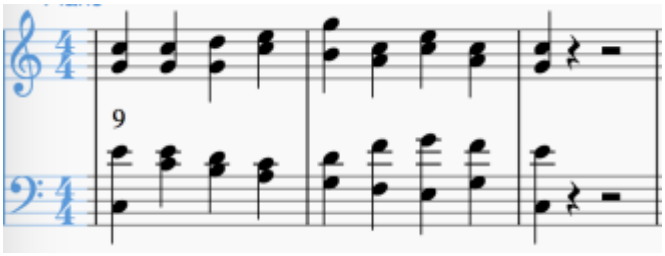
4. 

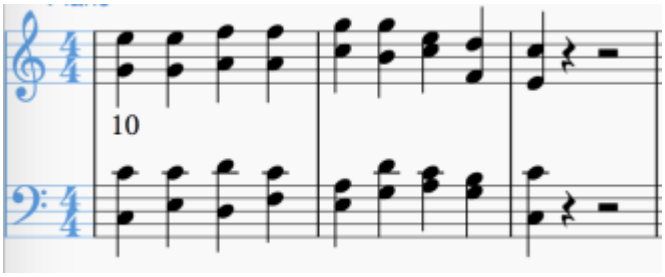
5. 

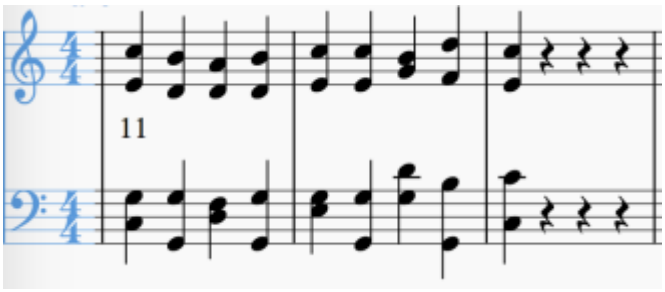
6. 

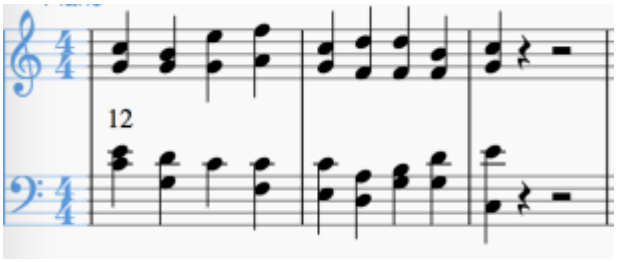
7. 

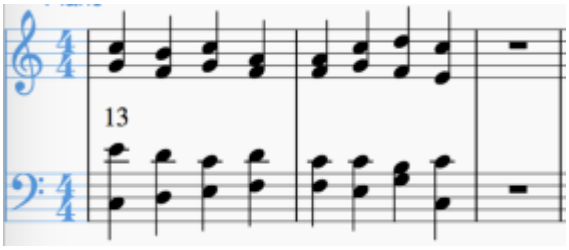
8. 

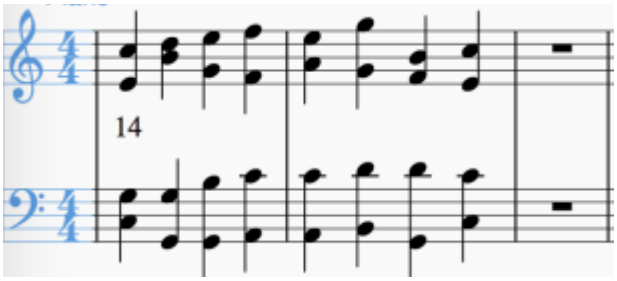
9. 

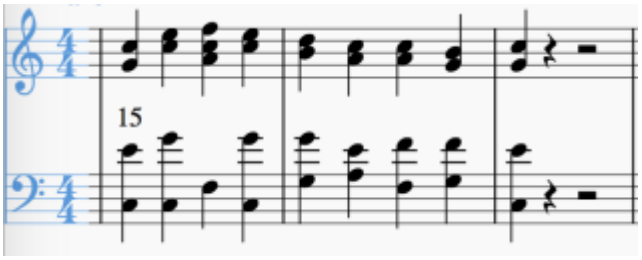
10. 

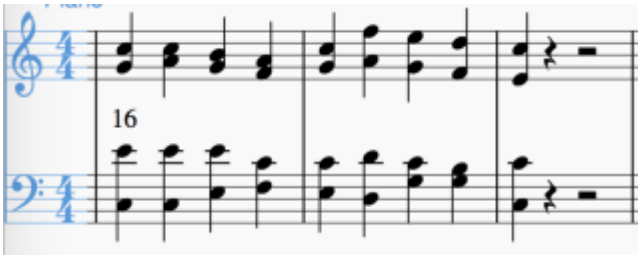
11. 

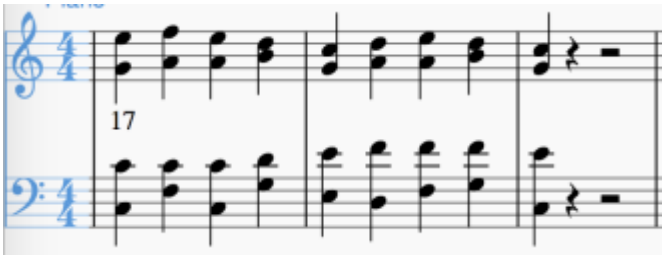
12. 

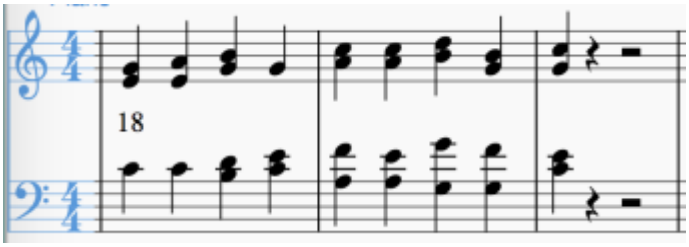
13. 

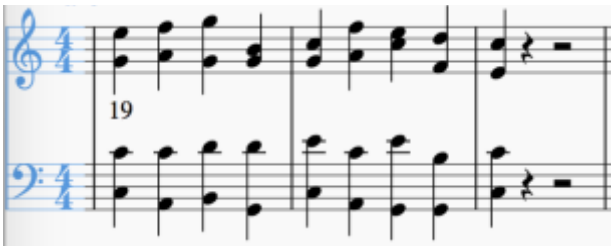
14. 

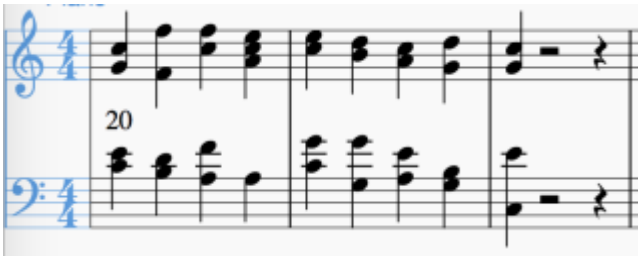
15. 

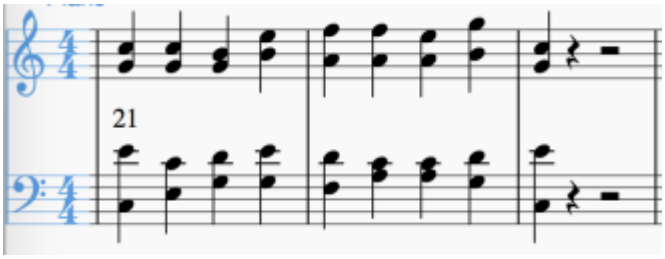
16. 

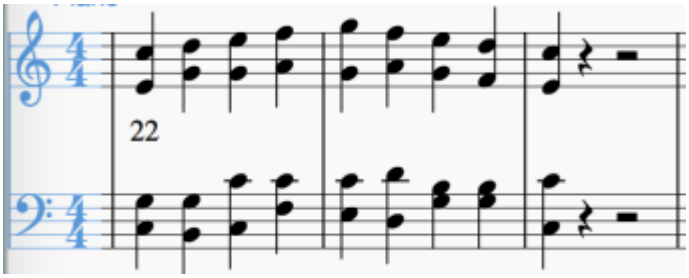
17. 

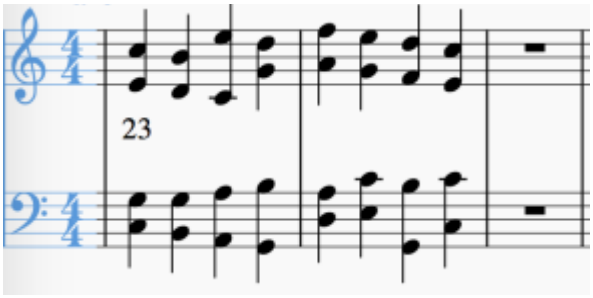
18. 

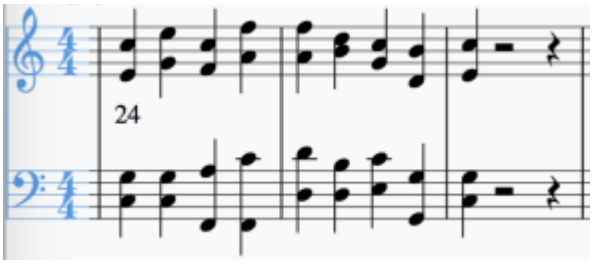
19. 

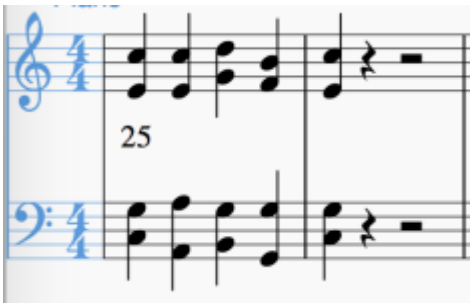
20. 

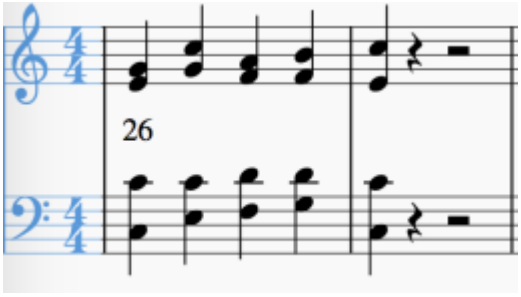
21. 

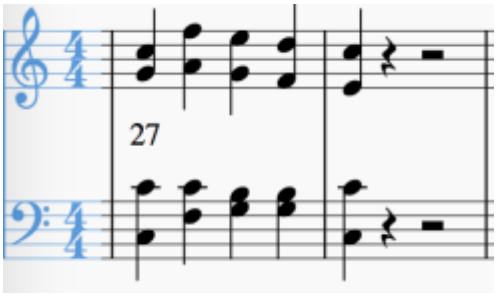
22. 

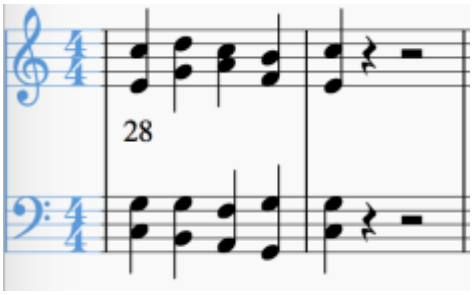
23. 

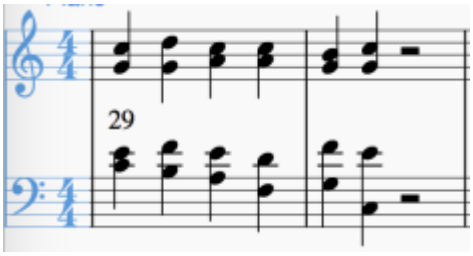
24. 

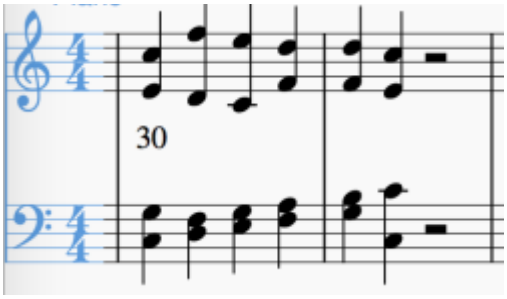
25. 

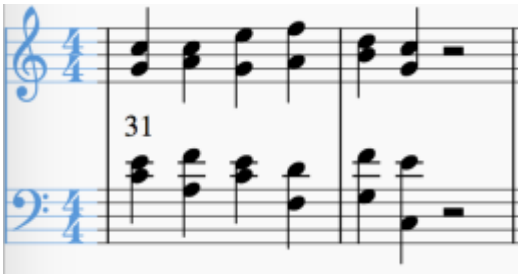
26. 

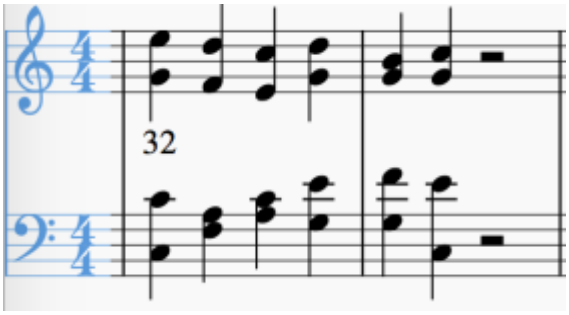
27. 

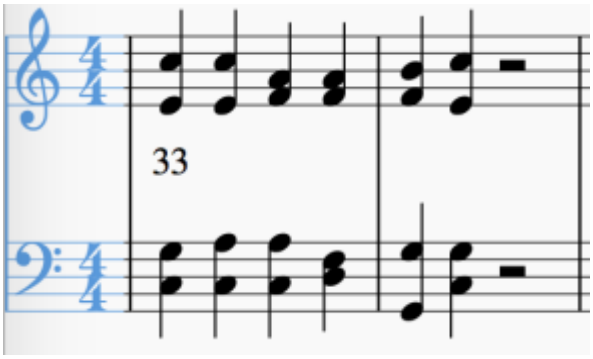
28. 

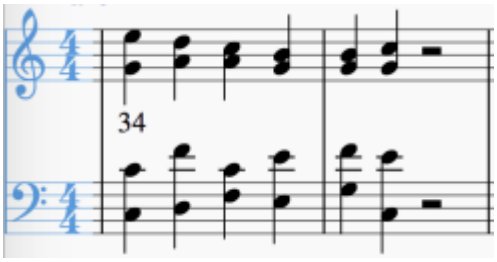
29. 

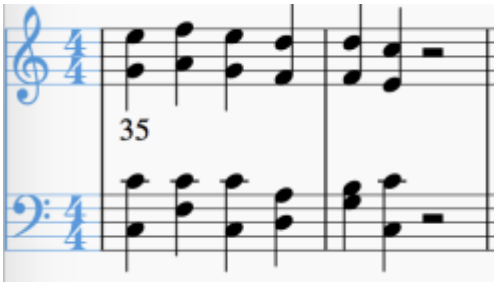
30. 

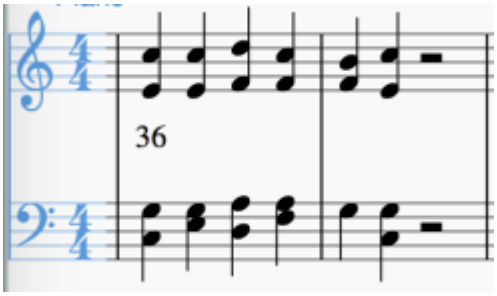
31. 

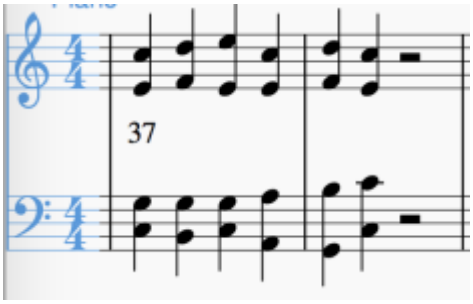
32. 

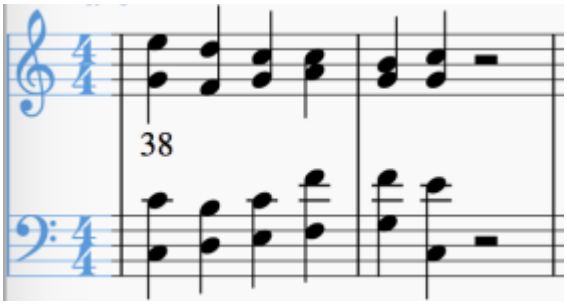
33. 

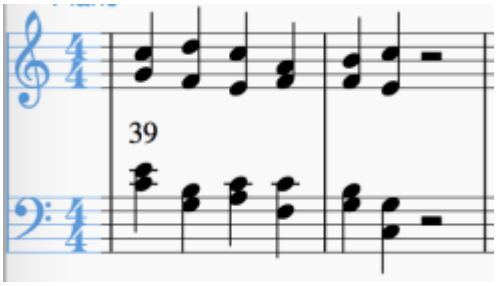
34. 

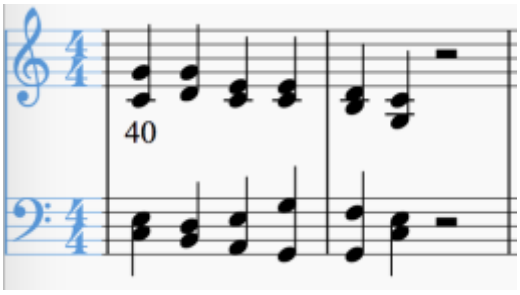
35. 

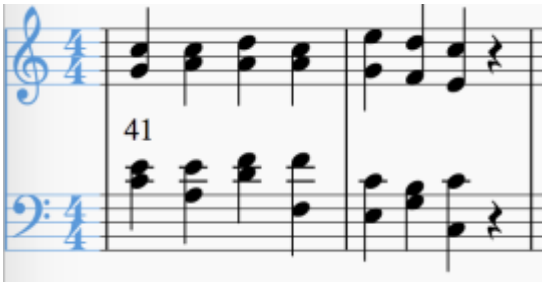
36. 

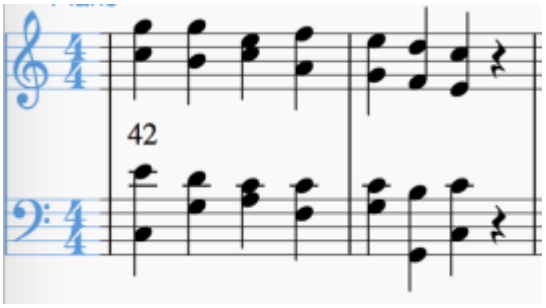
37. 

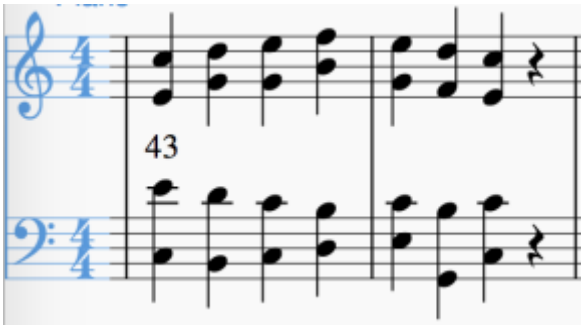
38. 

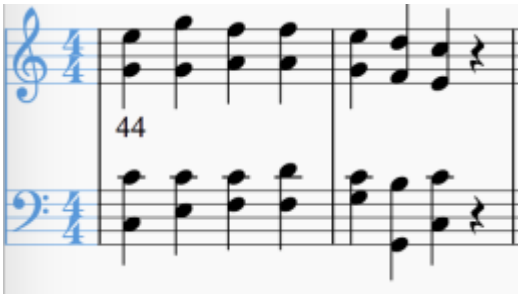
39. 

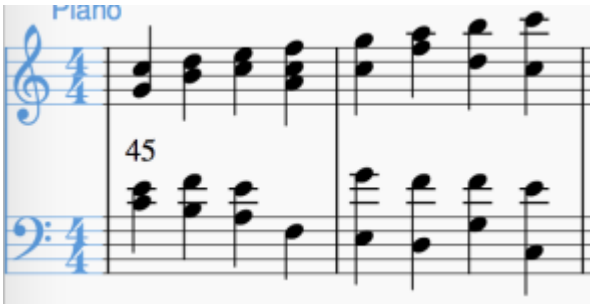
40. 

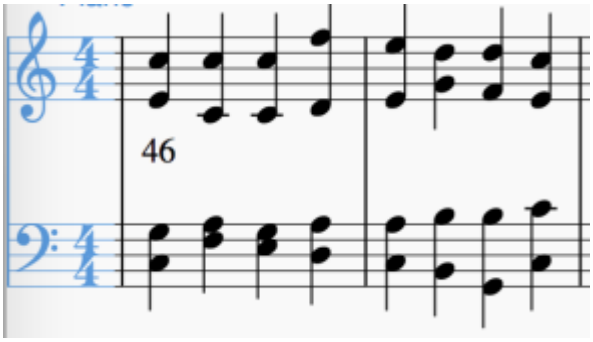
41. 

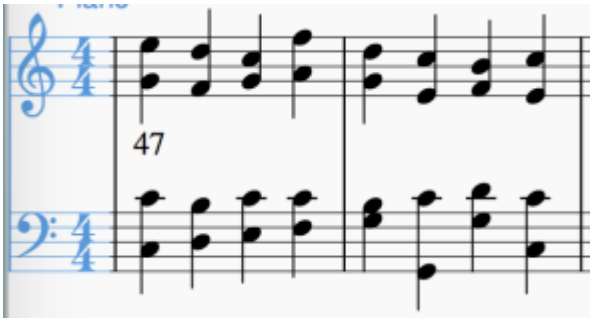
42. 

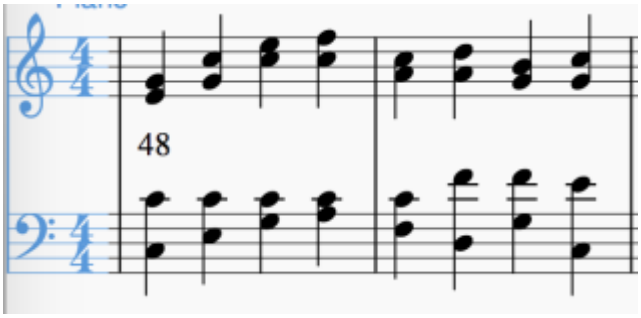
43. 

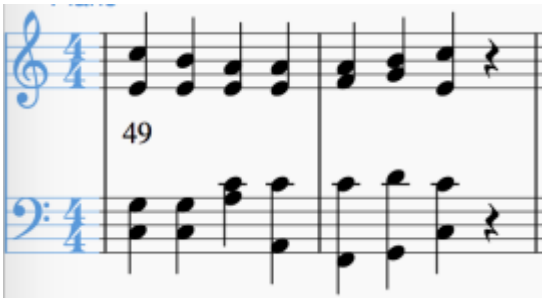
44. 

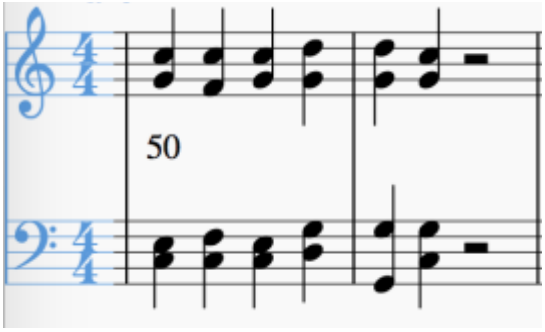
45. 

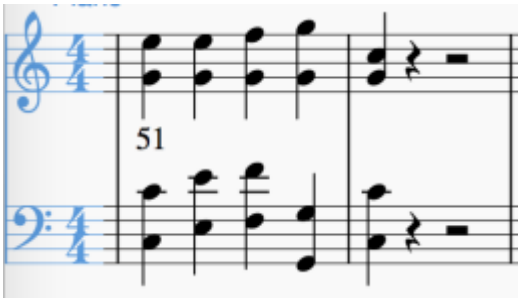
46. 

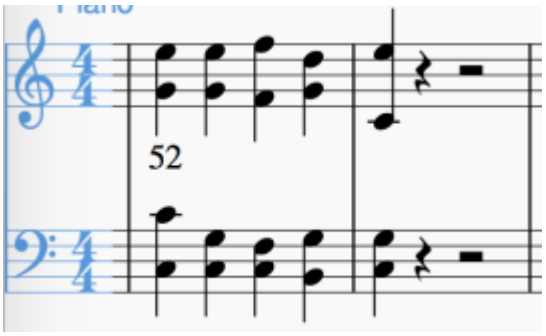
47. 

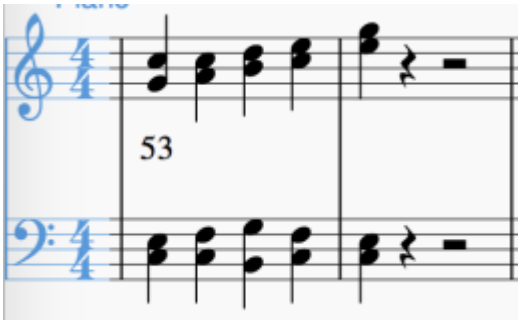
48. 

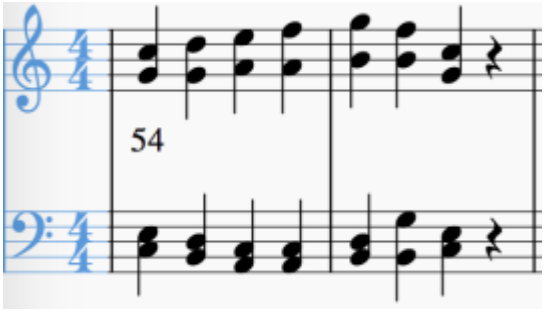
49. 

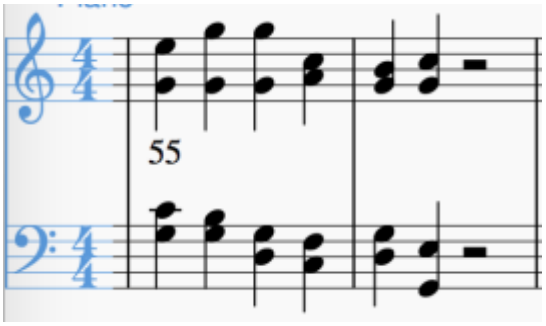
50. 

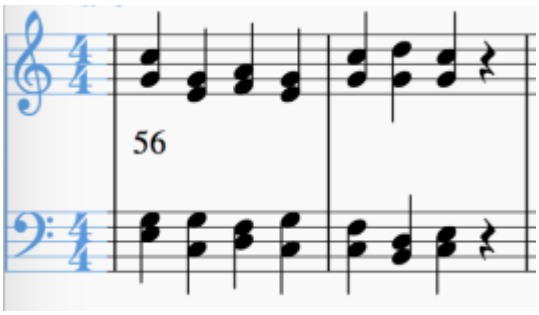
51. 

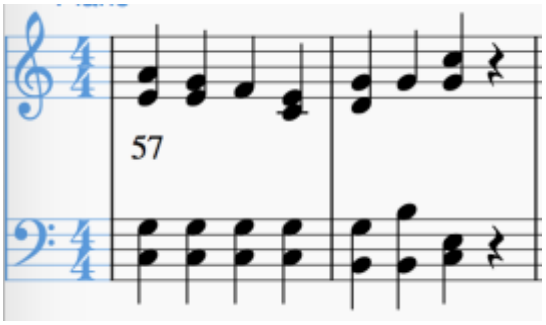
52. 

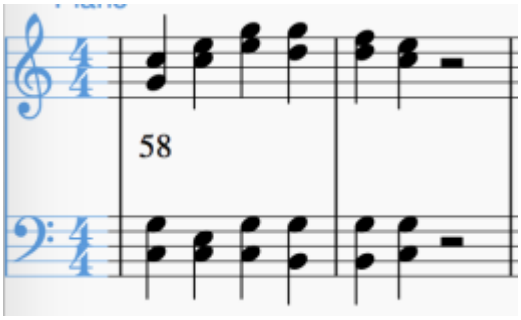
53. 

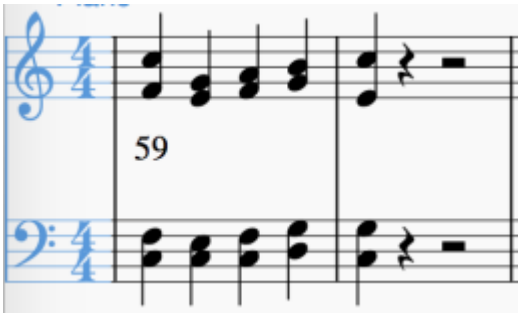
54. 

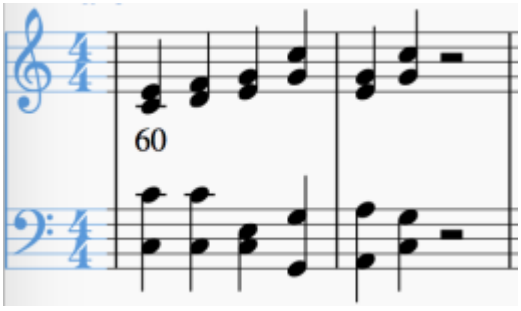
55. 

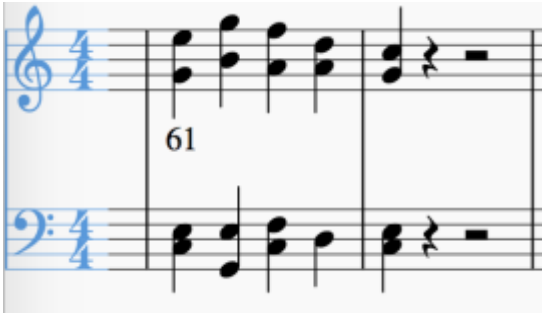
56. 

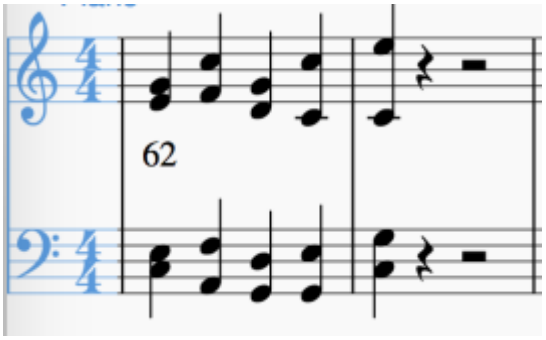
57. 

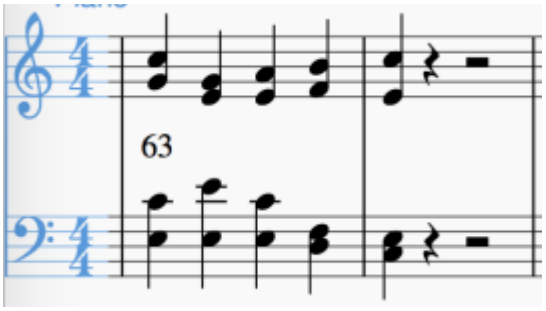
58. 

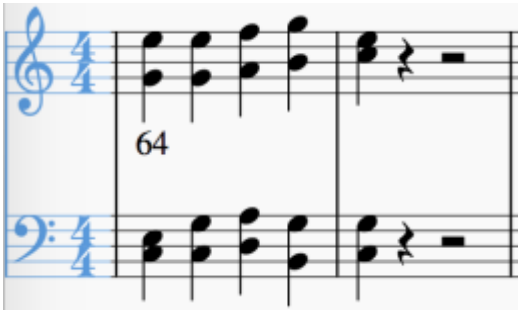
59. 

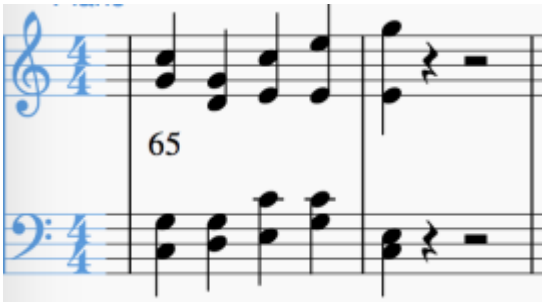
60. 

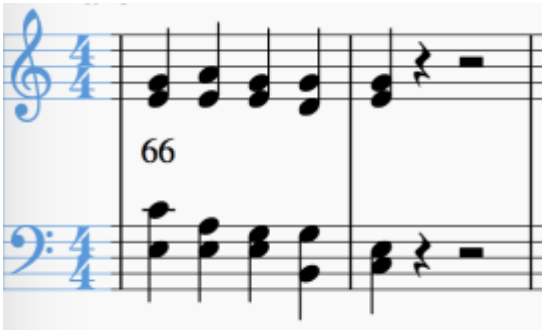
61. 

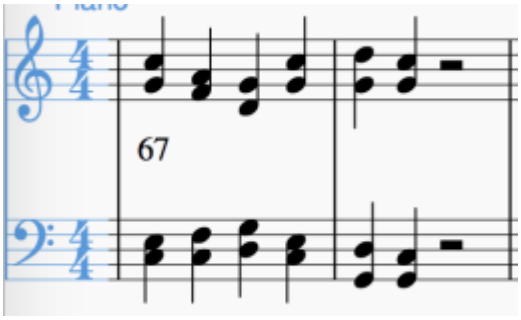
62. 

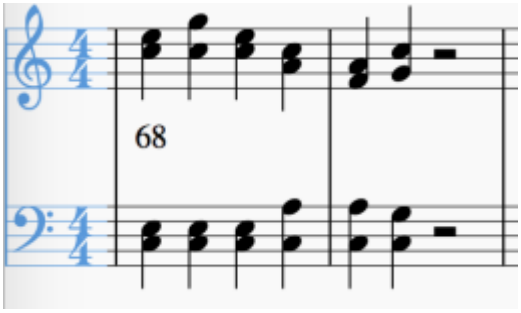
63. 

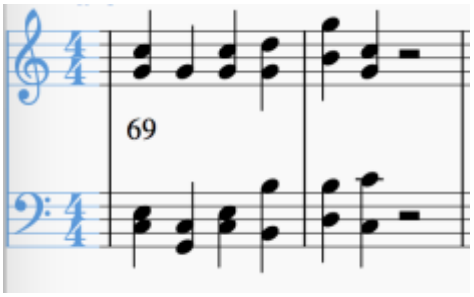
64. 

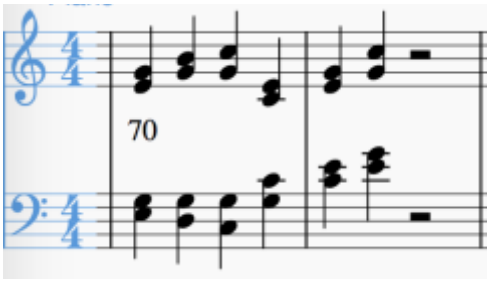
65. 

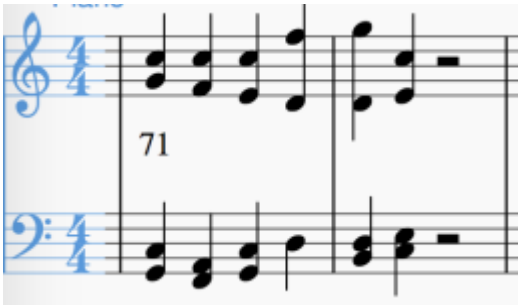
66. 

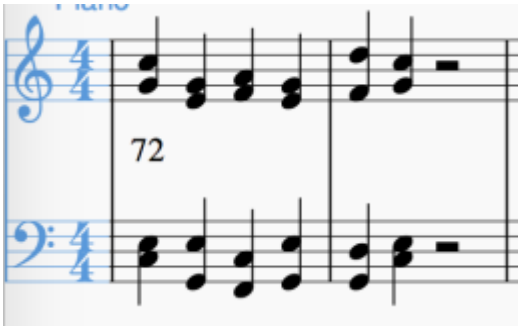
67. 

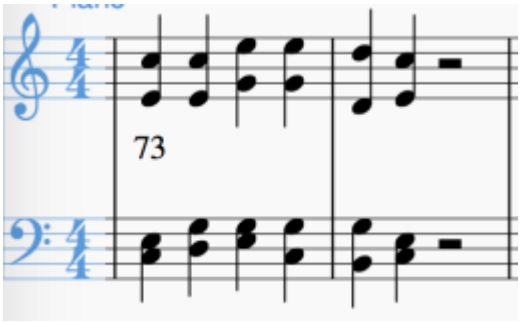
68. 

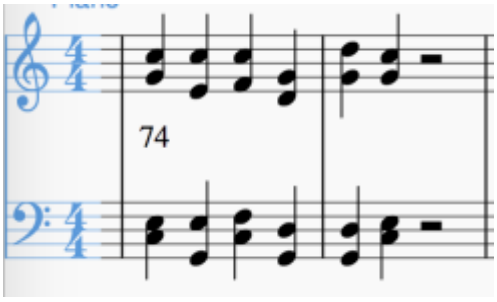
69. 

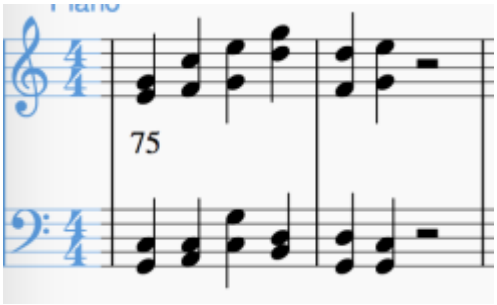
70. 

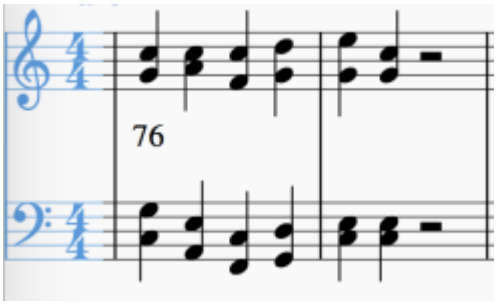
71. 

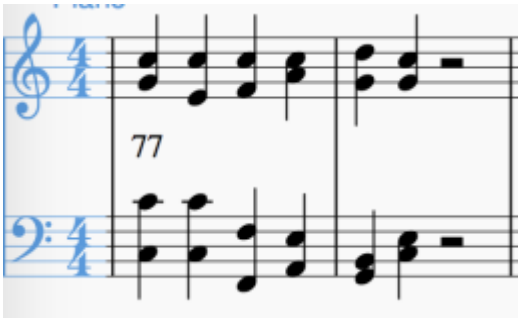
72. 

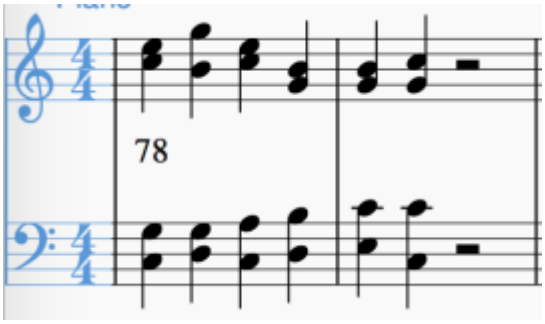
73. 

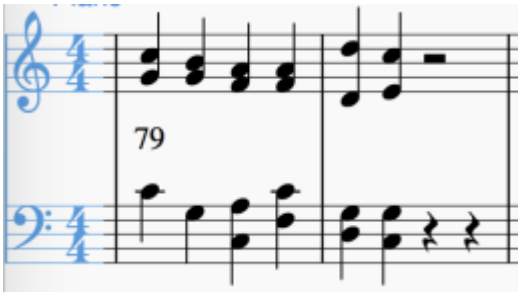
74. 

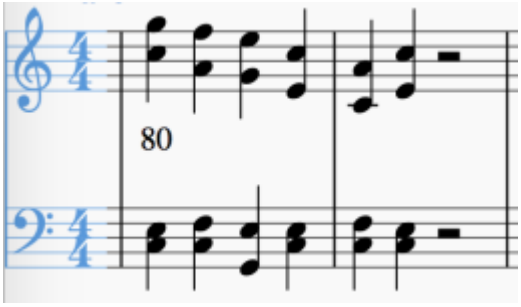
75. 

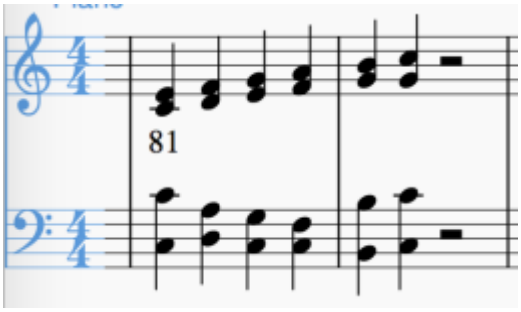
76. 

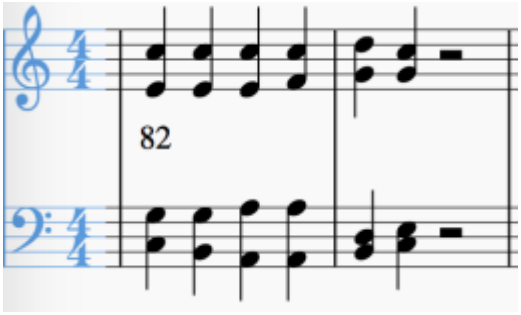
77. 

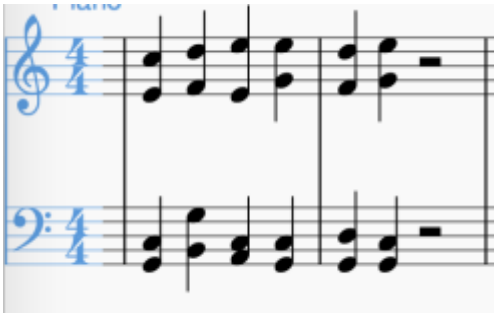
78. 

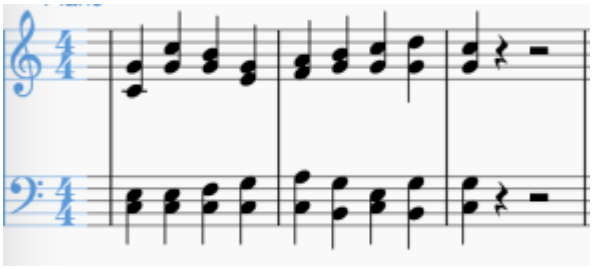
79. 

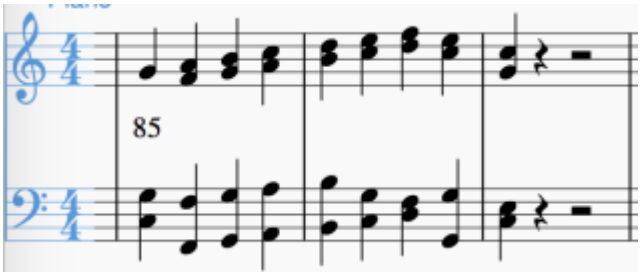
80. 

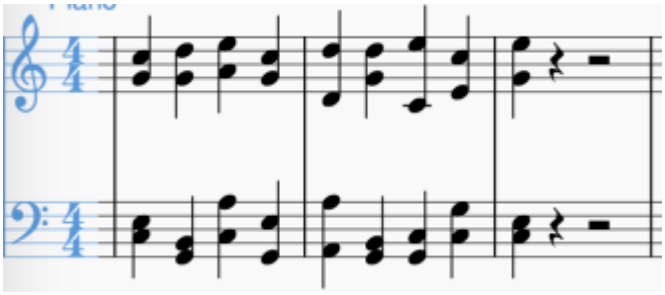
81. 

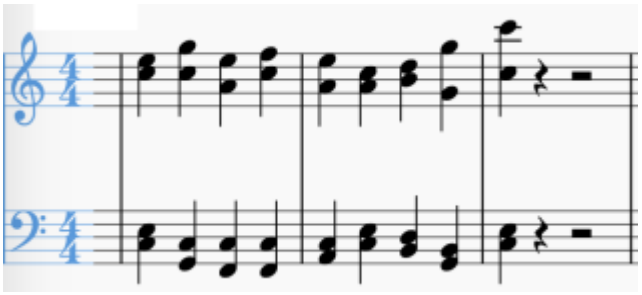
82. 

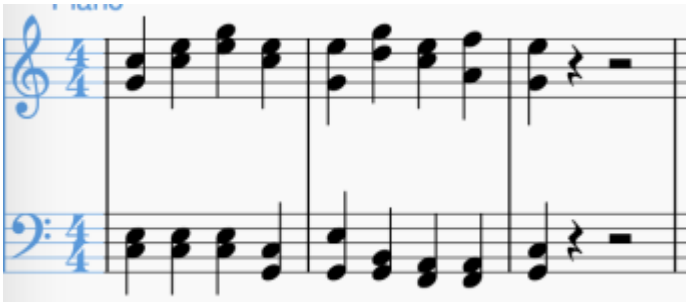
83. 

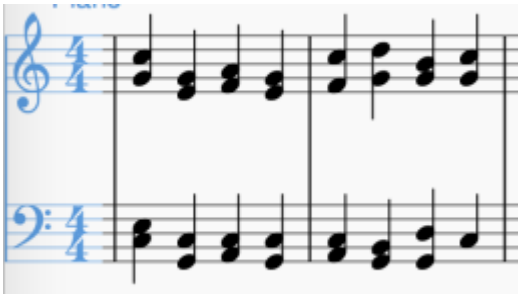
84. 

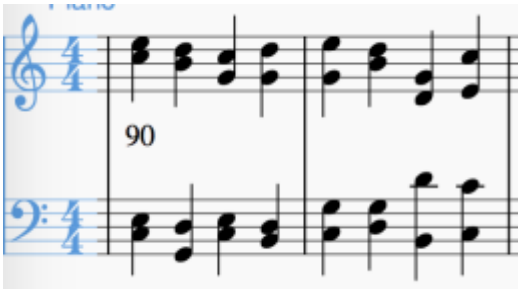
85. 

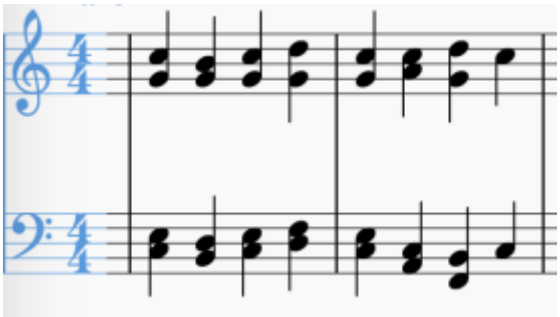
86. 

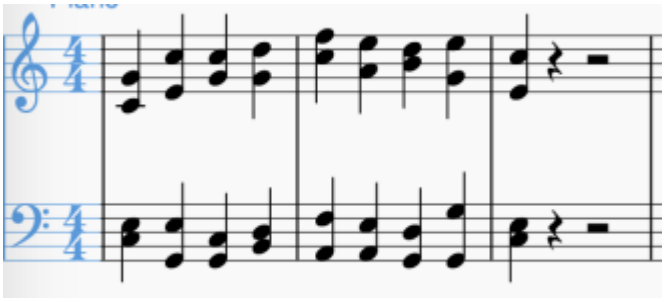
87. 

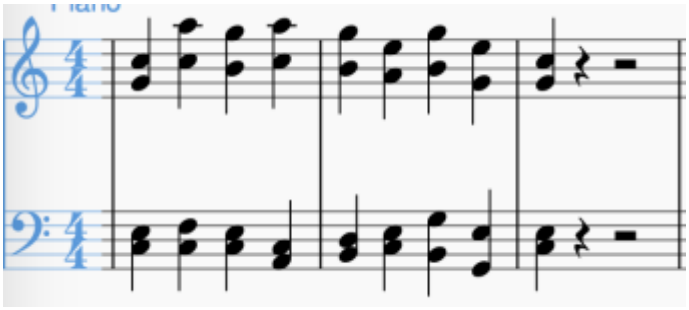
88. 

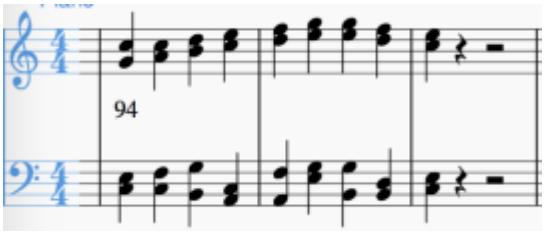
89. 

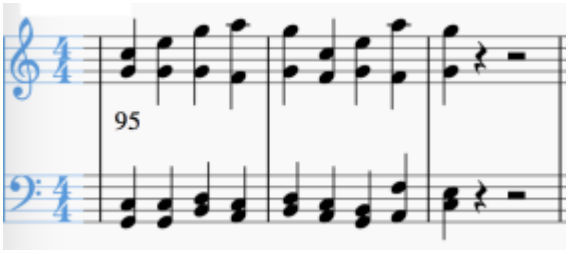
90. 

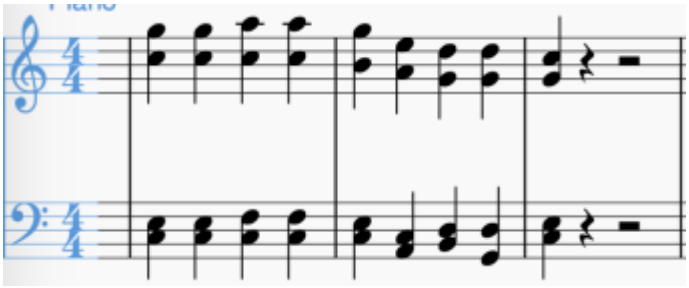
91. 

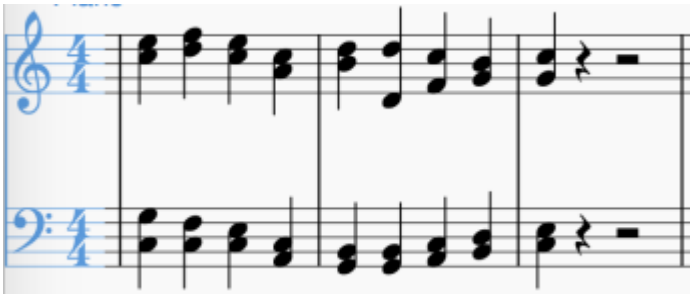
92. 

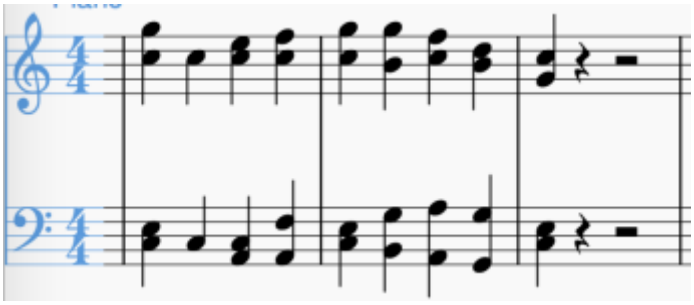
93. 

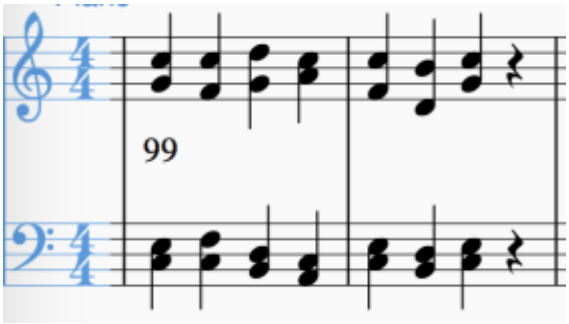
94. 

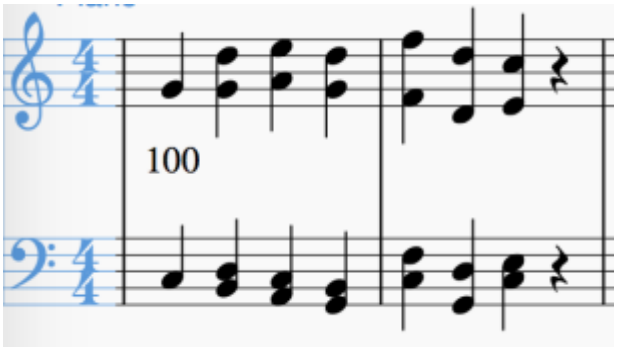
95. 

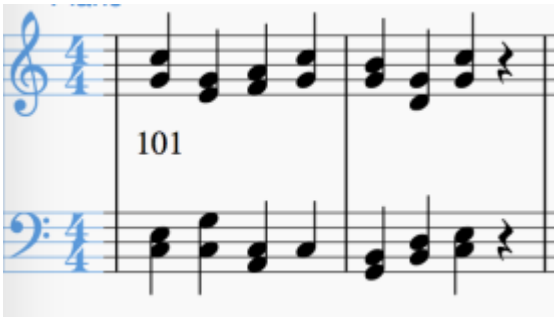
96. 

97. 

98. 

99. 

100. 

101. 

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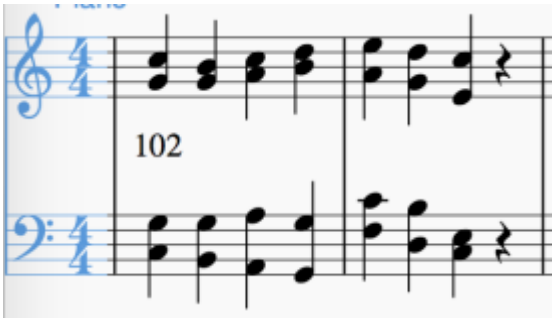

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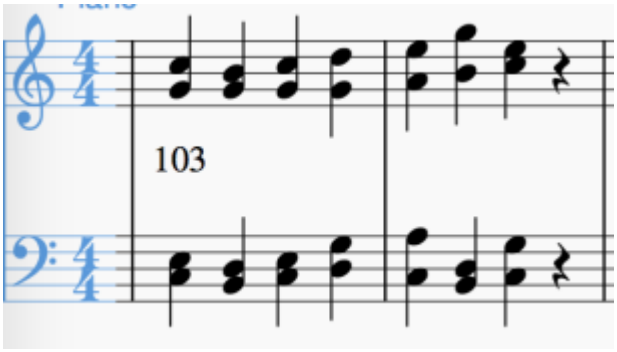

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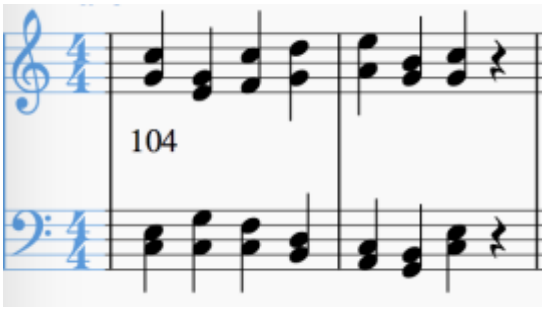

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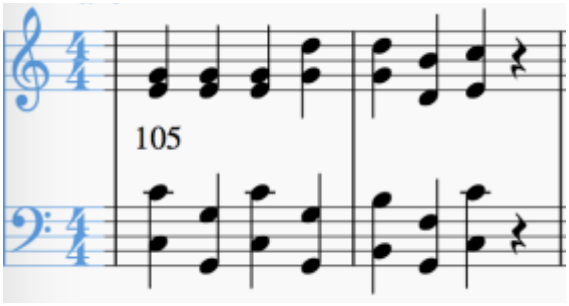

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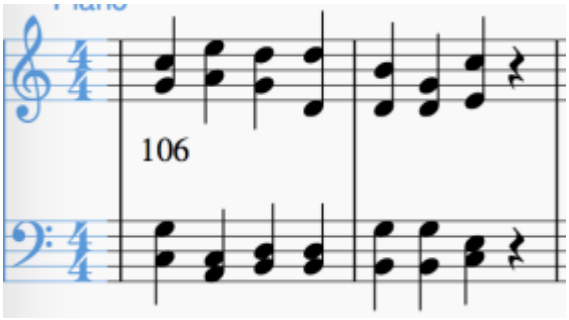

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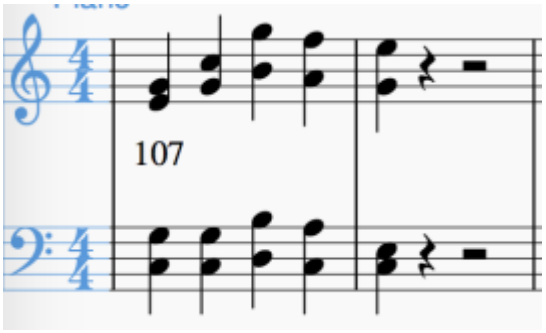

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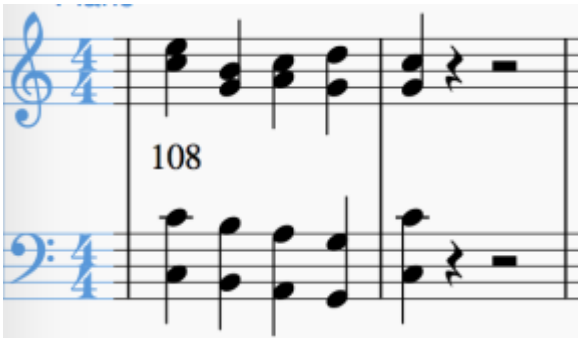

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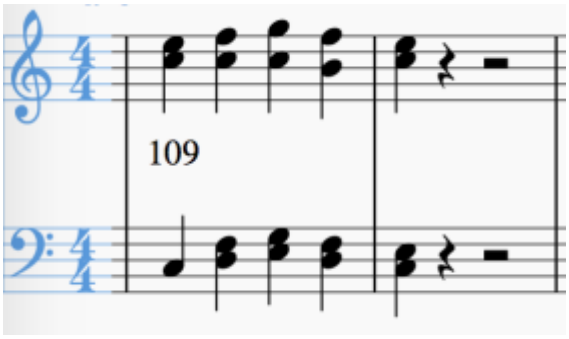

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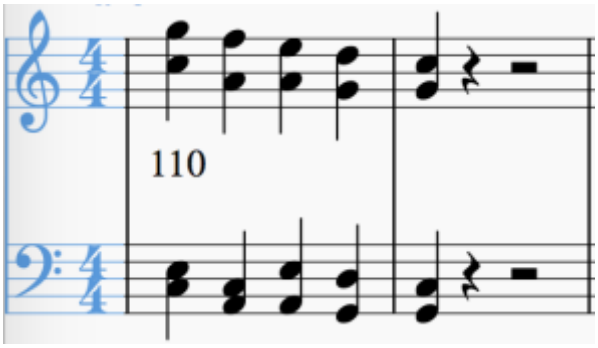
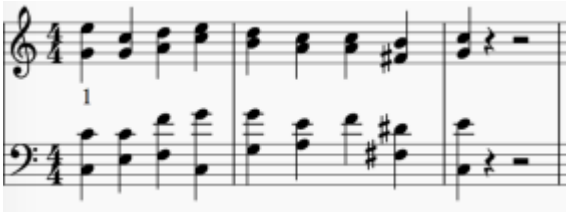
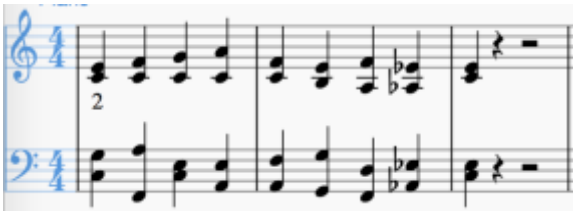
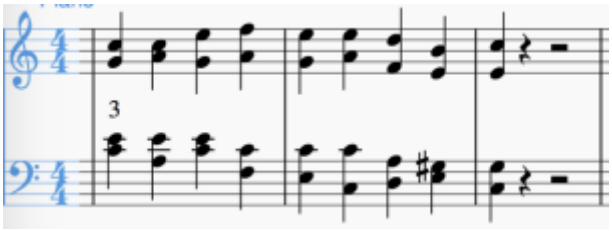
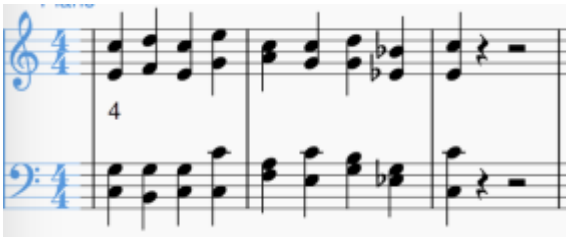


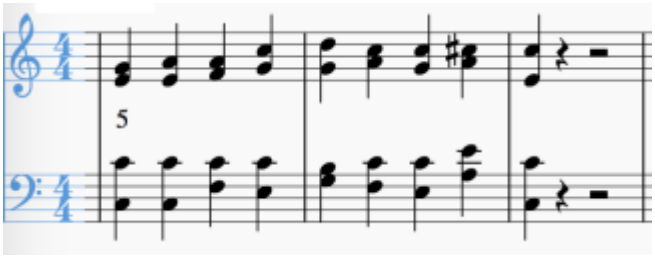
Out-of-Key Chord Progressions

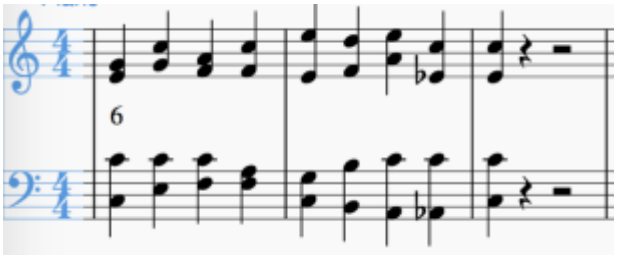
1. 

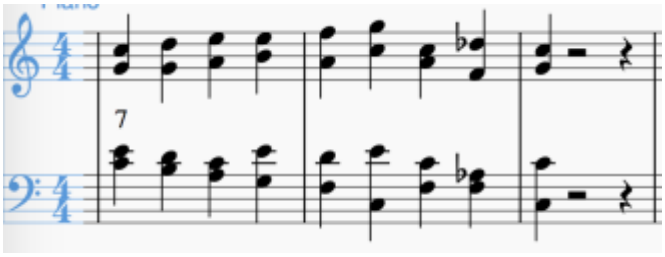
2. 

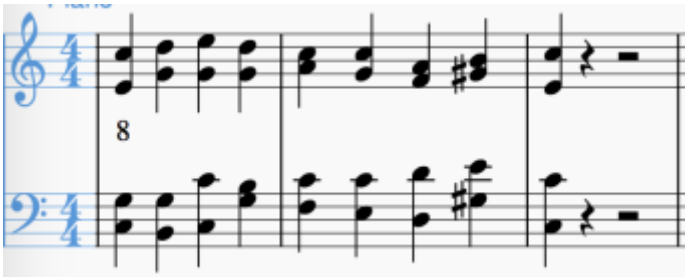
3. 

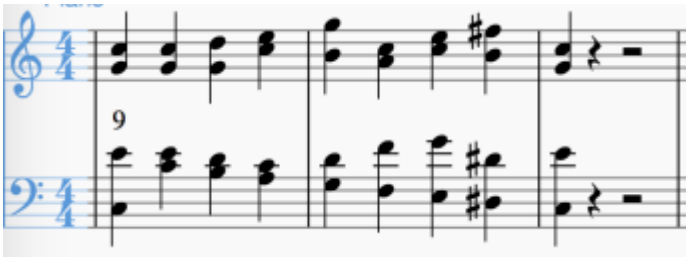
4. 

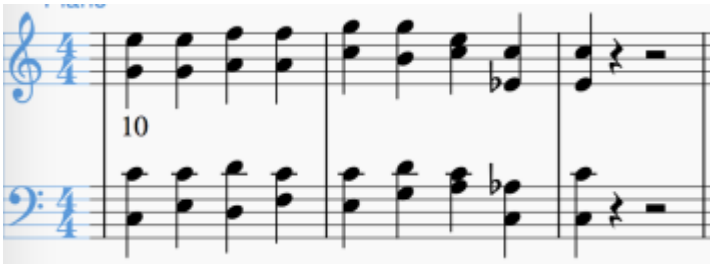
5. 

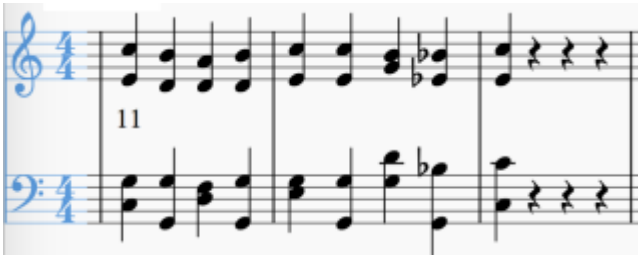
6. 

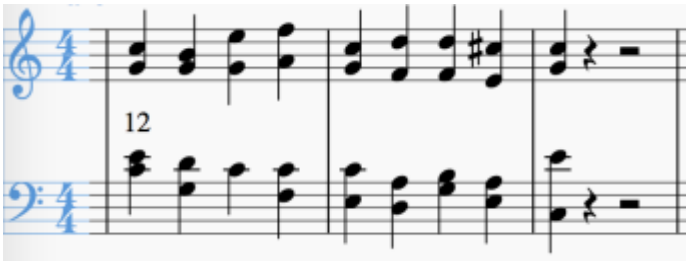
7. 

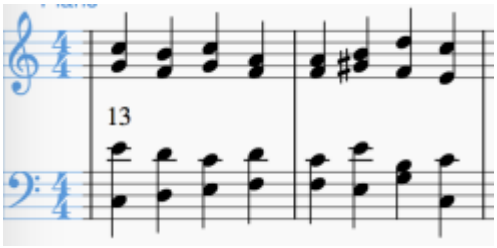
8. 

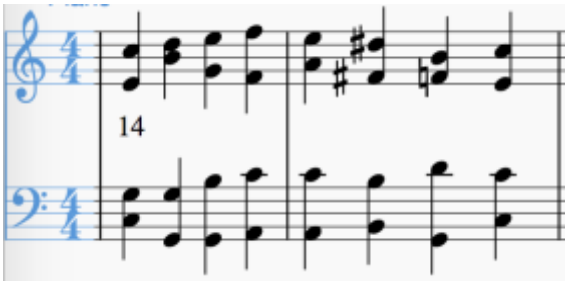
9. 

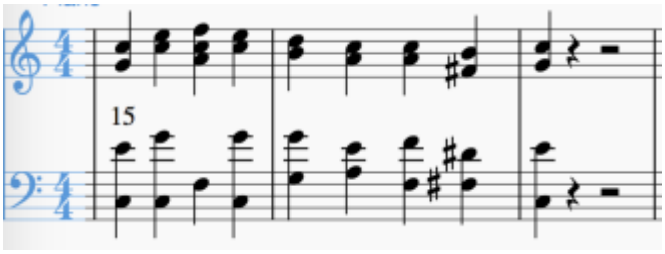
10. 

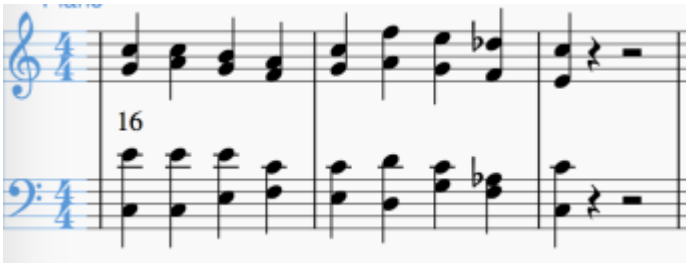
11. 

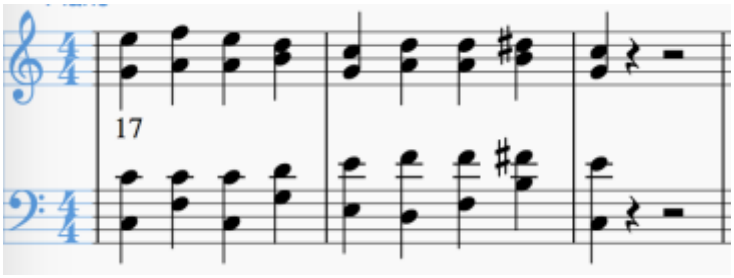
12. 

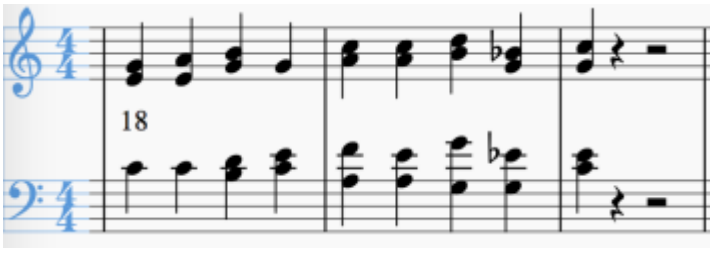
13. 

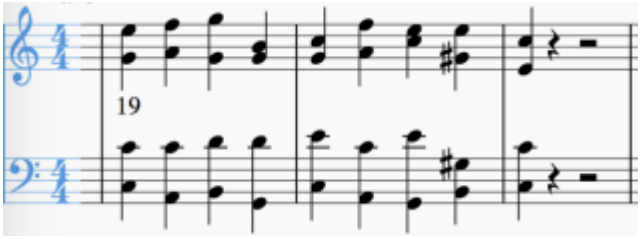
14. 

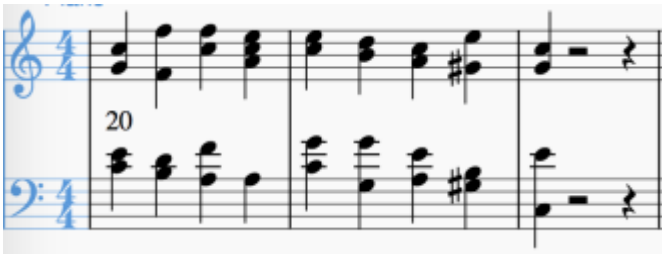
15. 

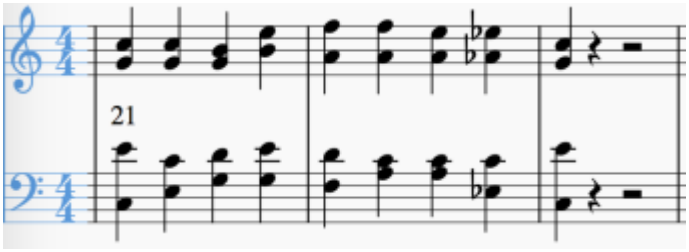
16. 

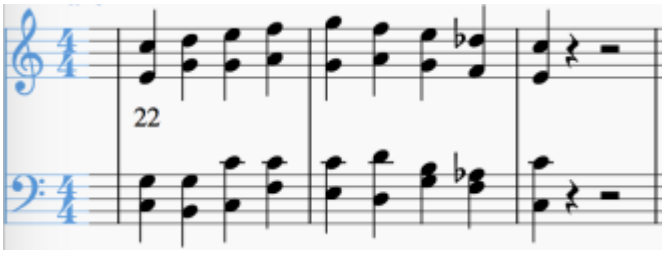
17. 

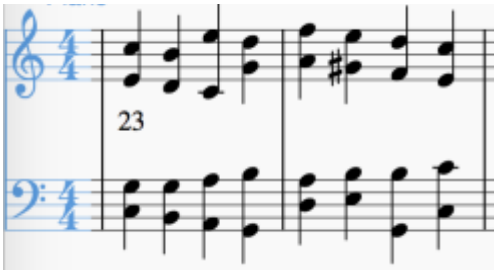
18. 

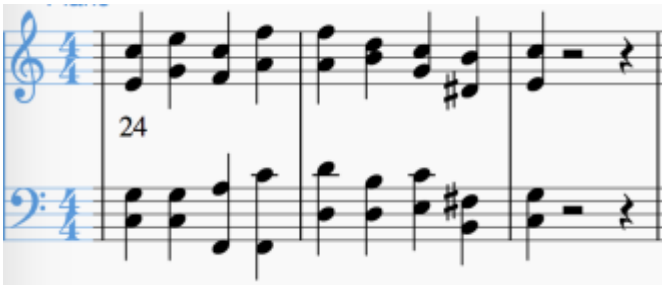
19. 

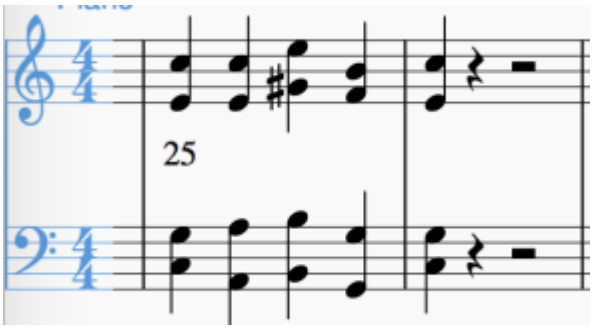
20. 

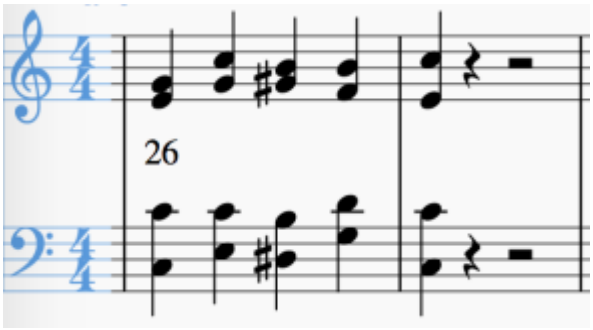
21. 

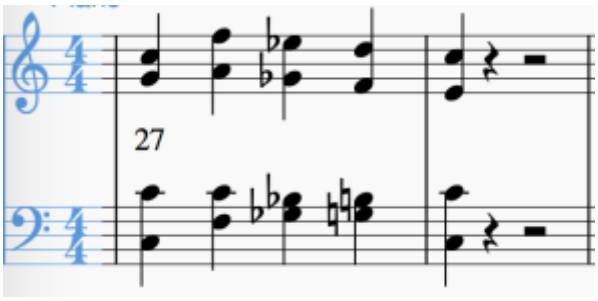
22. 

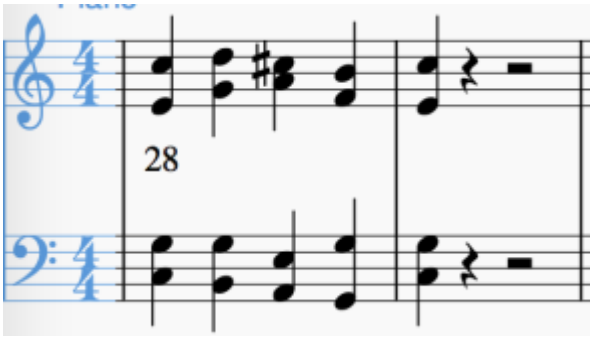
23. 

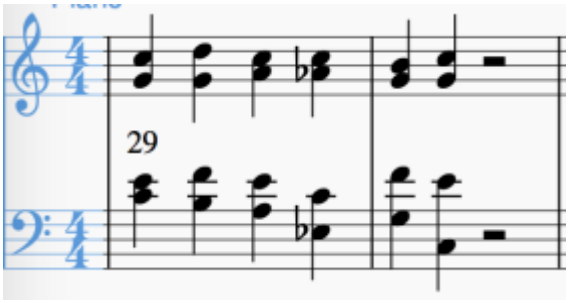
24. 

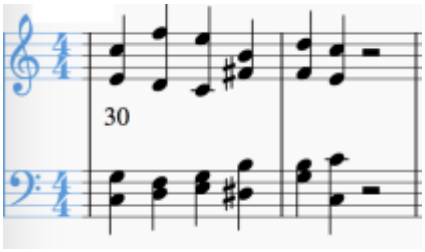
25. 

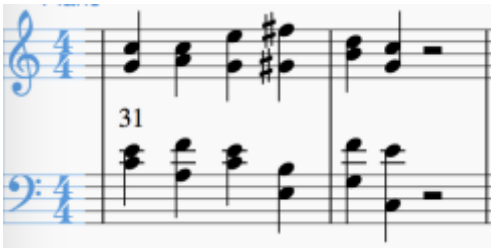
26. 

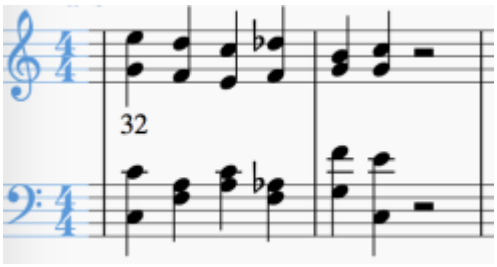
27. 

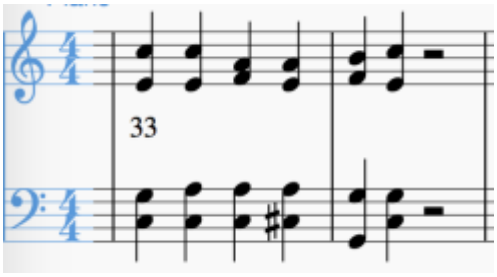
28. 

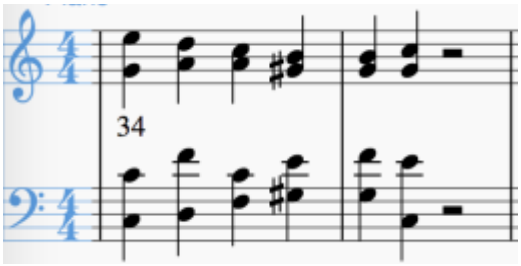
29. 

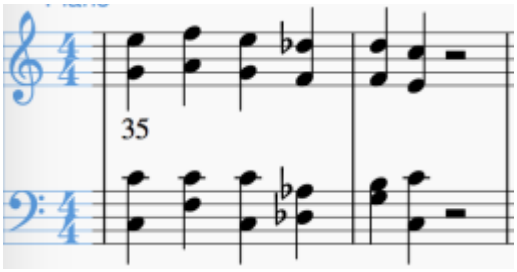
30. 

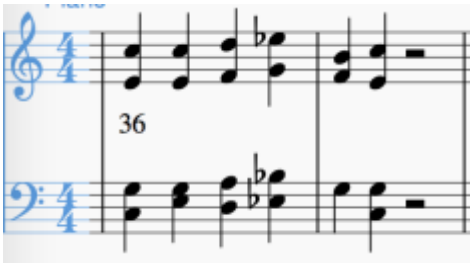
31. 

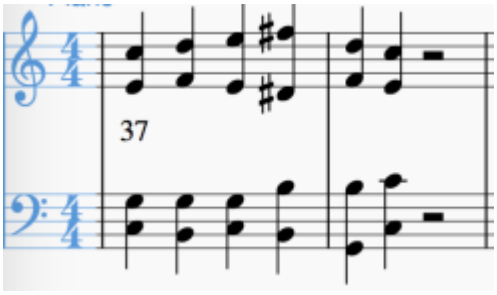
32. 

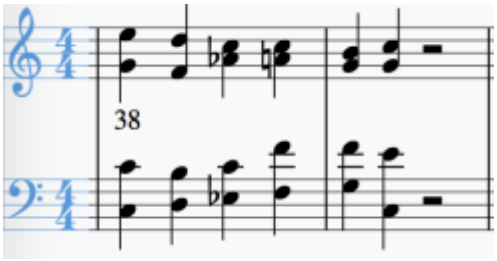
33. 

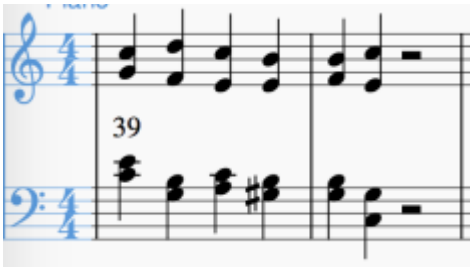
34. 

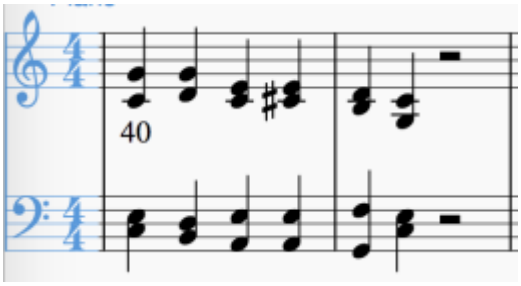
35. 

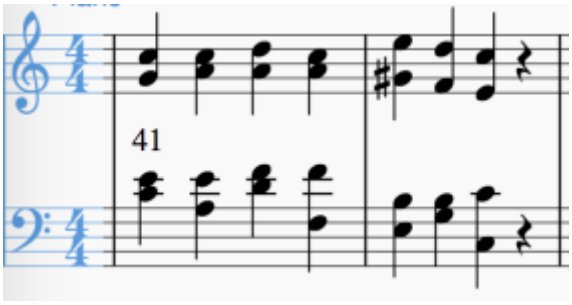
36. 

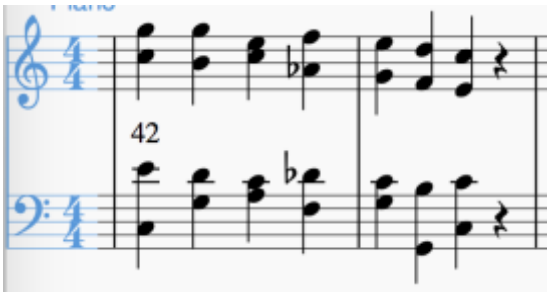
37. 

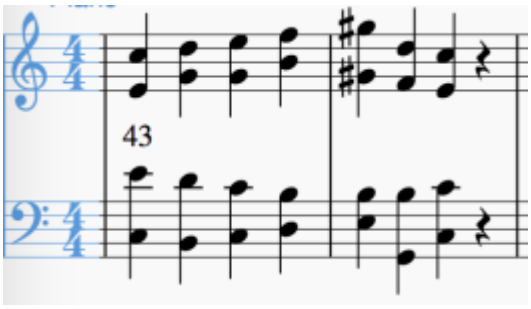
38. 

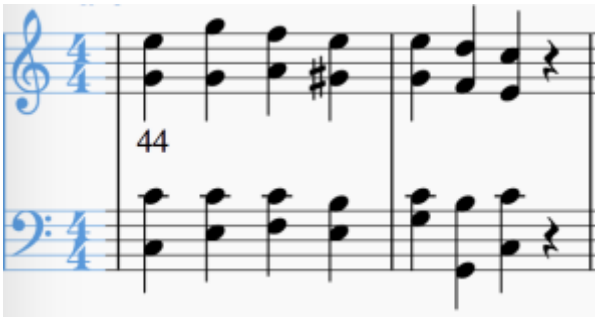
39. 

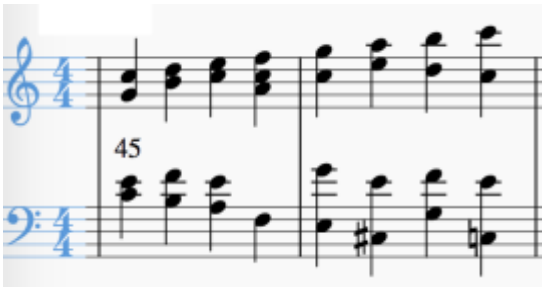
40. 

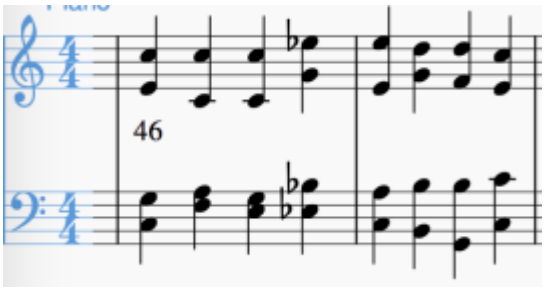
41. 

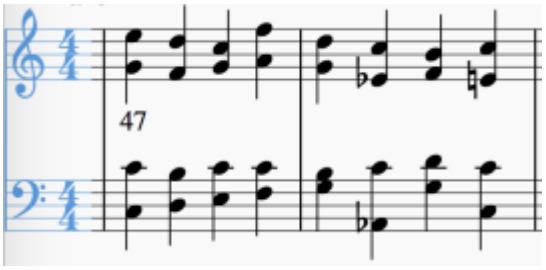
42. 

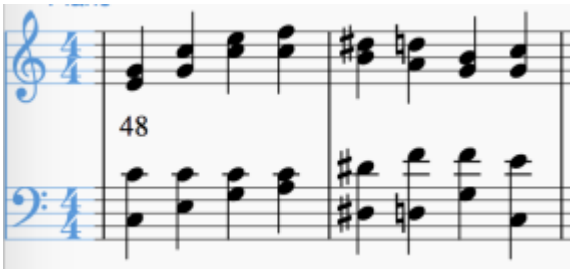
43. 

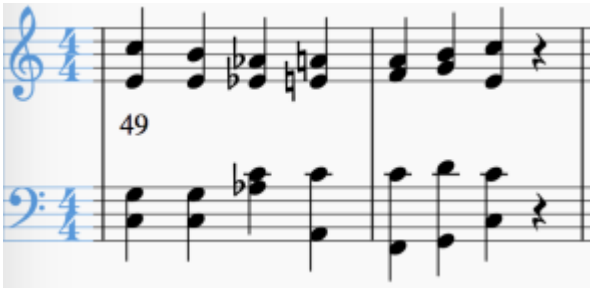
44. 

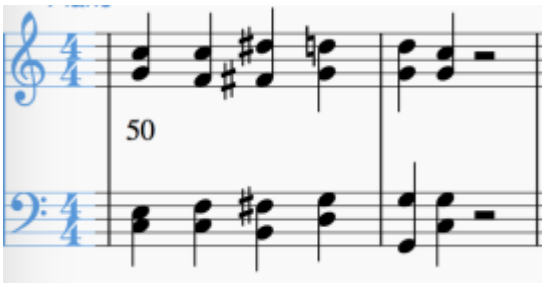
45. 

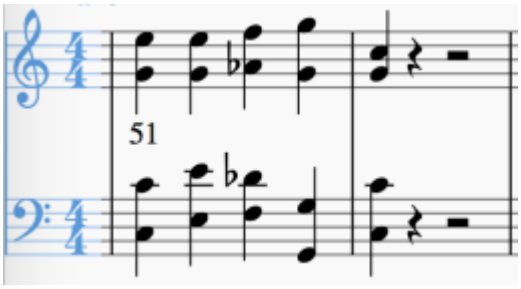
46. 

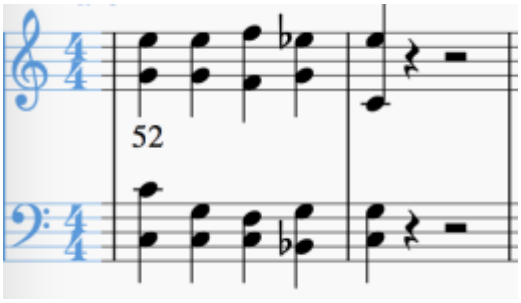
47. 

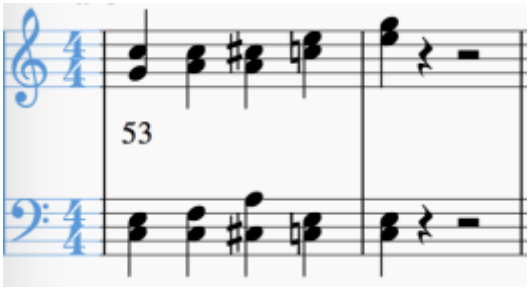
48. 

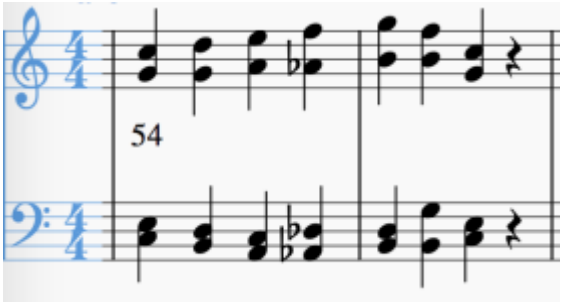
49. 

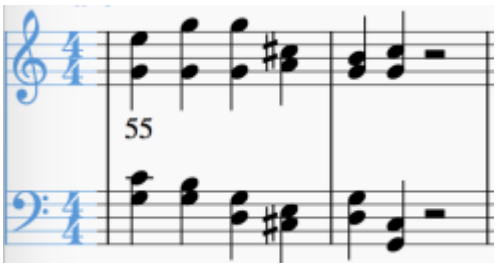
50. 

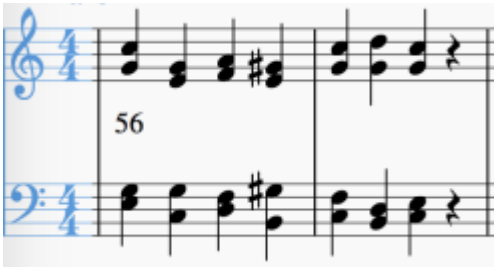
51. 

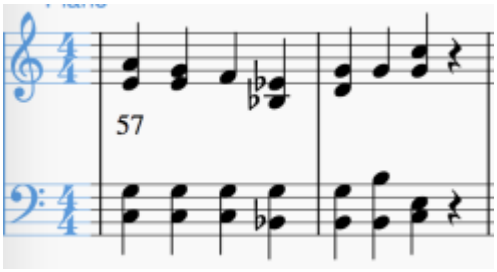
52. 

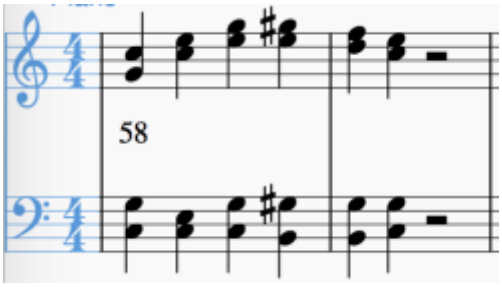
53. 

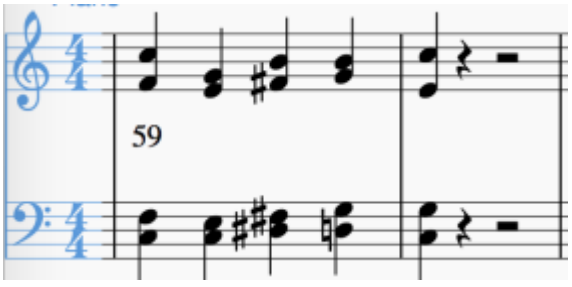
54. 

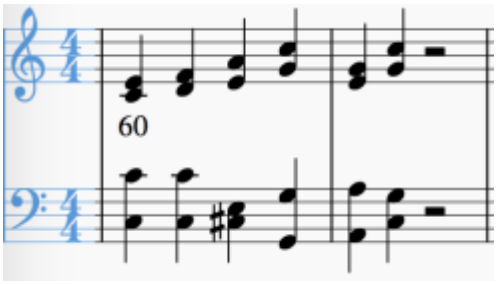
55. 

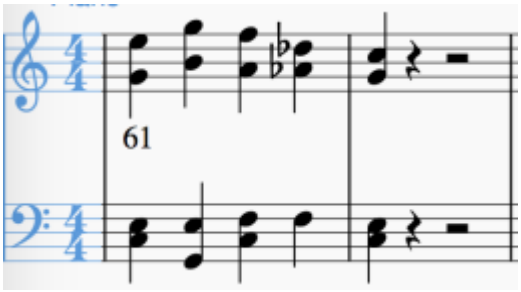
56. 

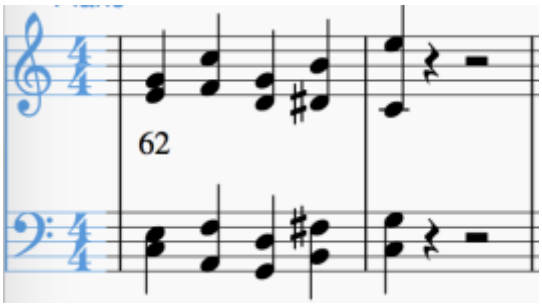
57. 

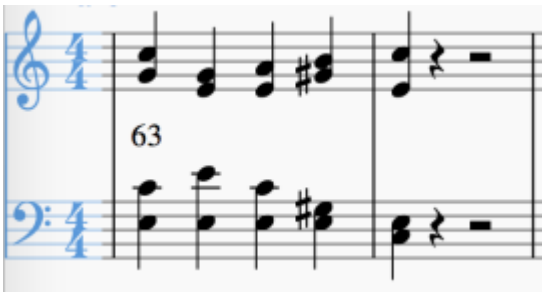
58. 

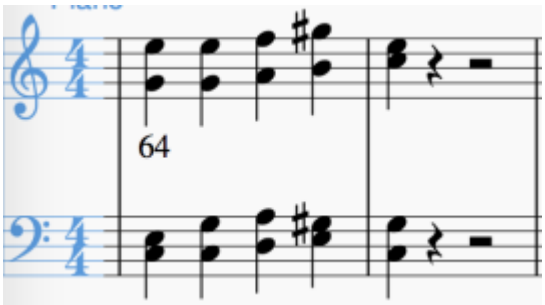
59. 

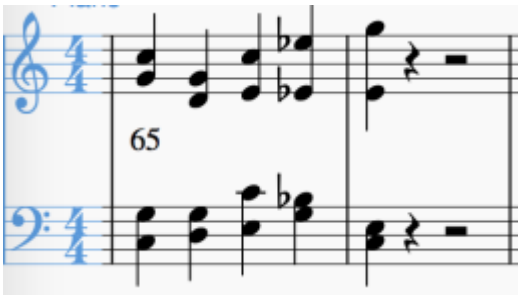
60. 

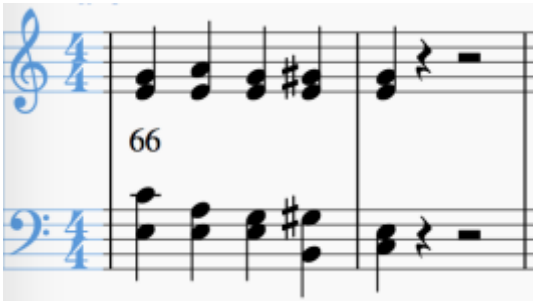
61. 

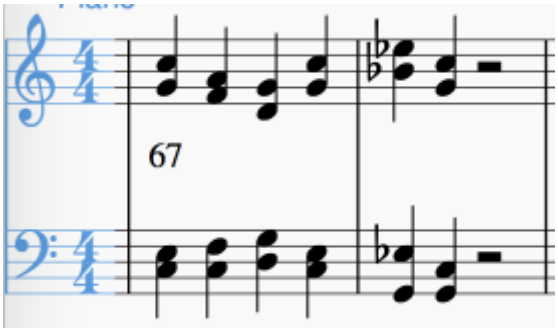
62. 

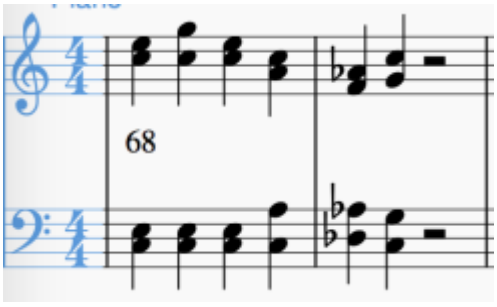
63. 

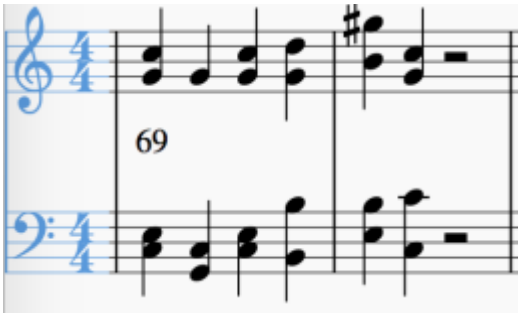
64. 

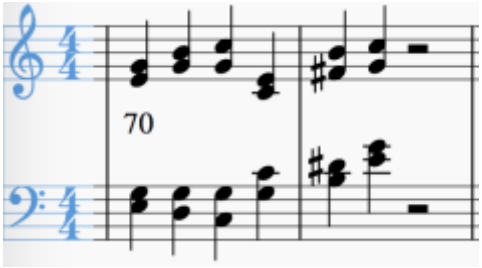
65. 

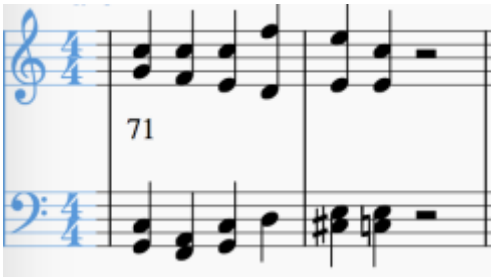
66. 

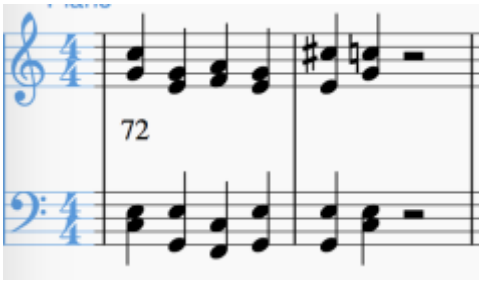
67. 

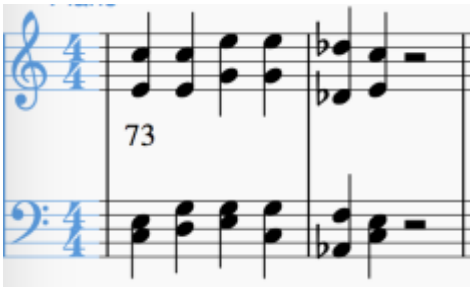
68. 

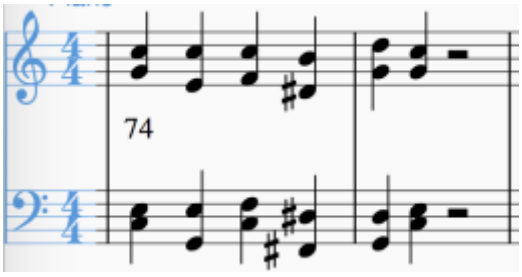
69. 

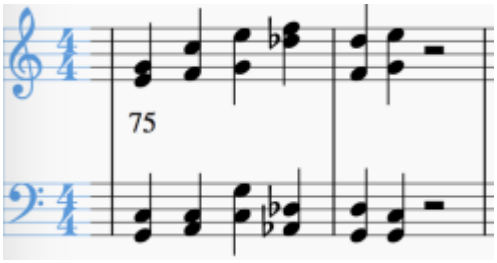
70. 

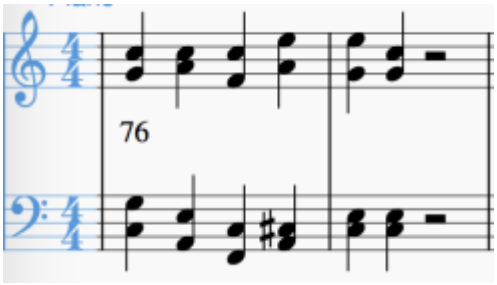
71. 

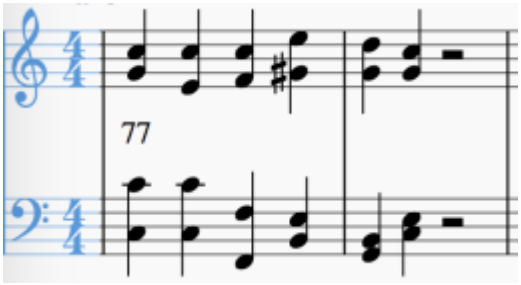
72. 

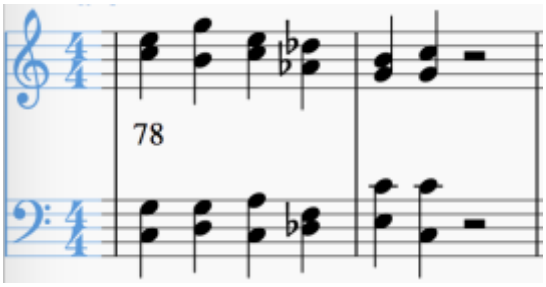
73. 

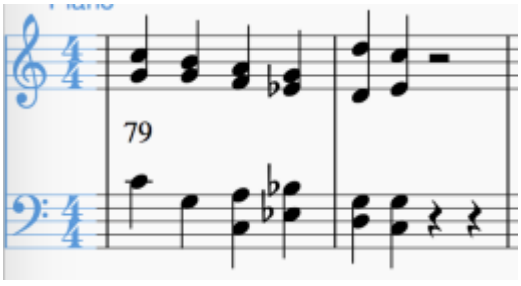
74. 

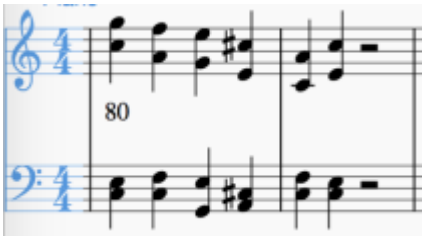
75. 

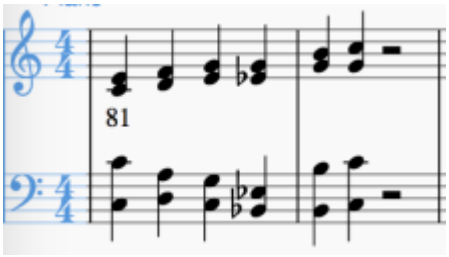
76. 

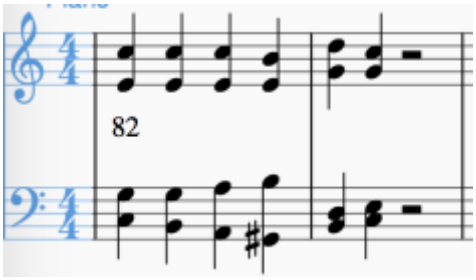
77. 

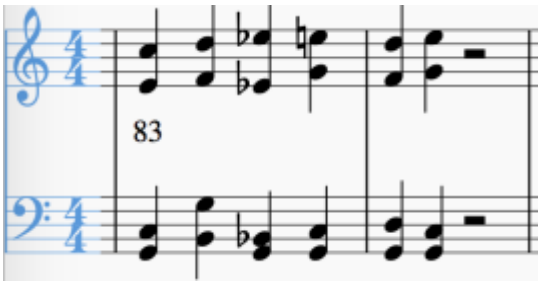
78. 

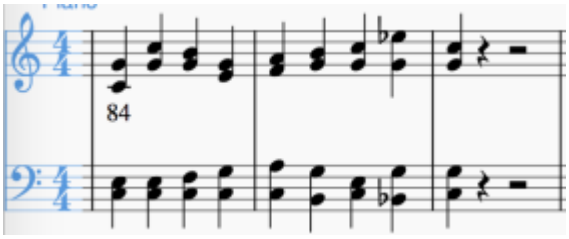
79. 

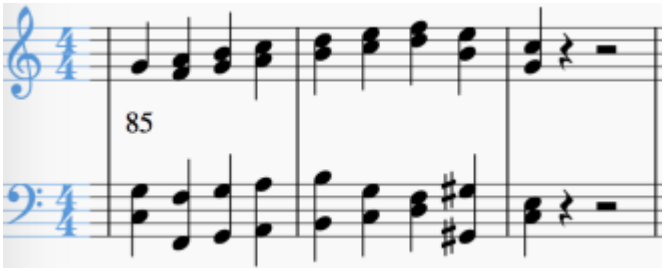
80. 

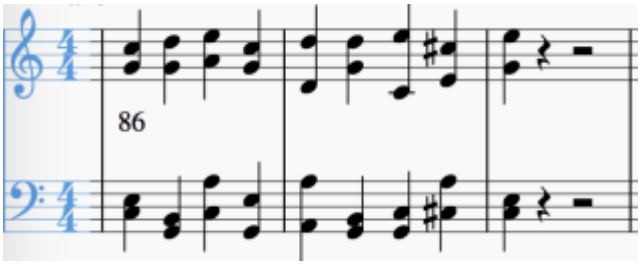
81. 

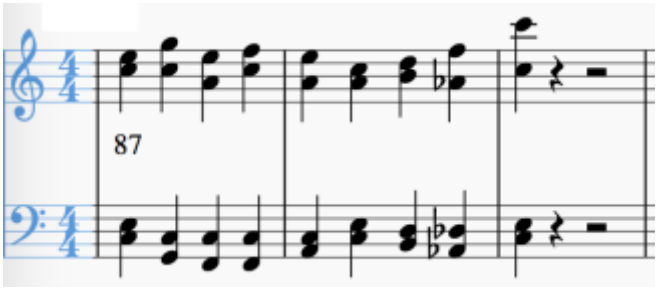
82. 

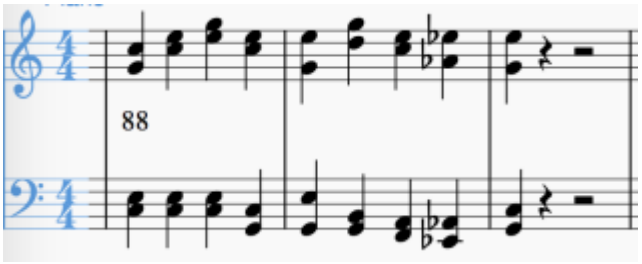
83. 

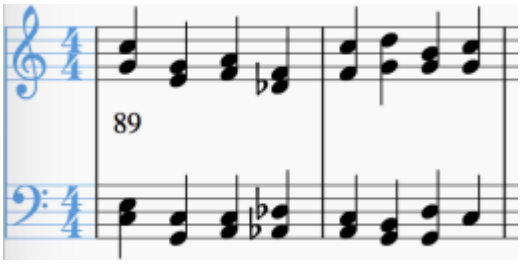
84. 

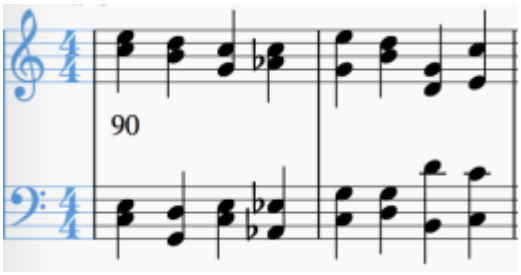
85. 

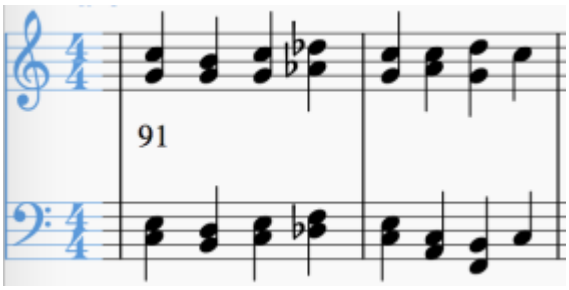
86. 

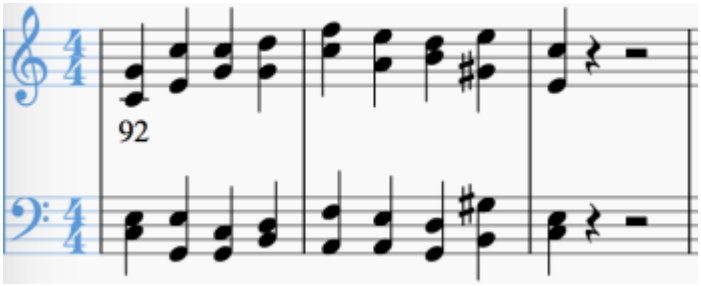
87. 

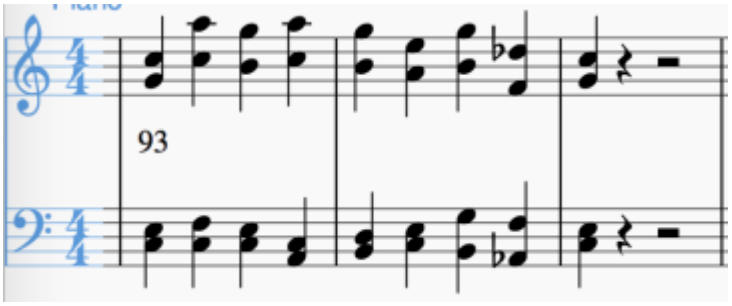
88. 

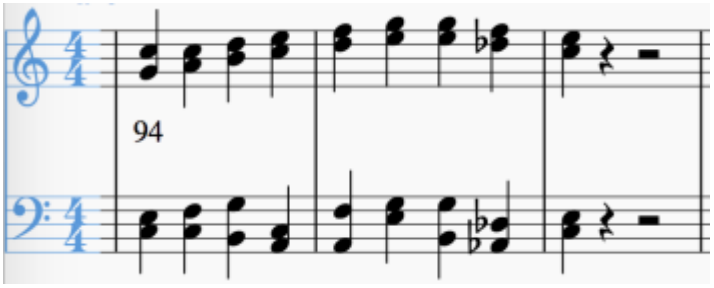
89. 

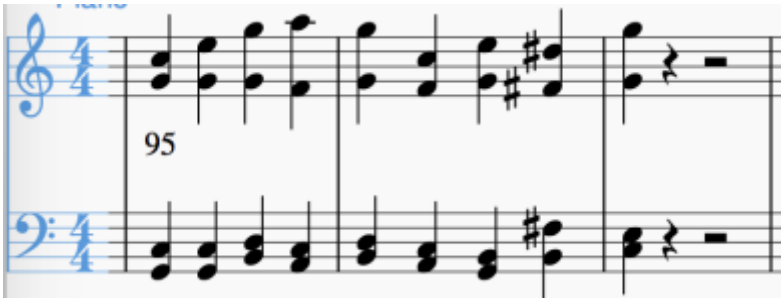
90. 

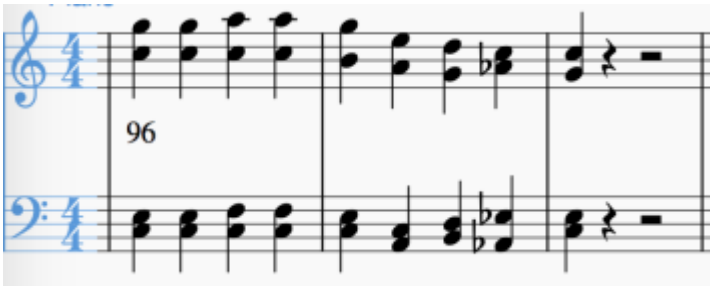
91. 

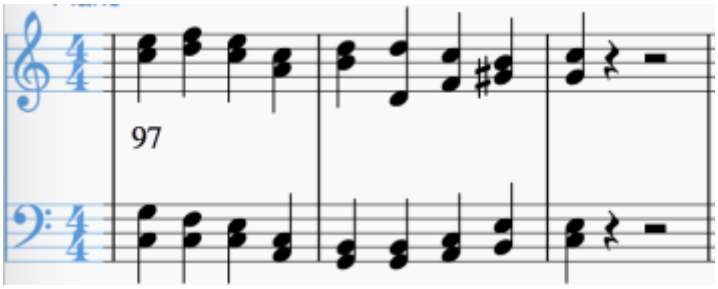
92. 

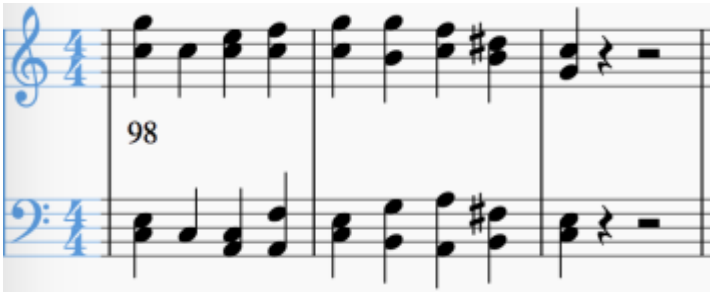
93. 

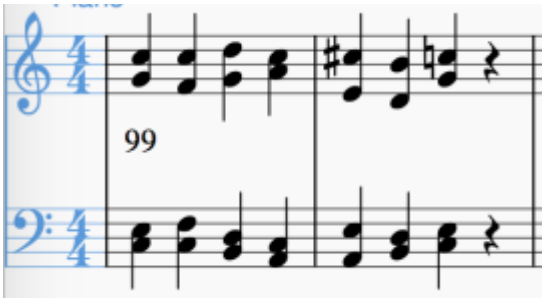
94. 

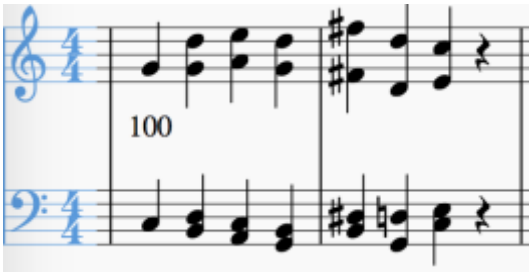
95. 

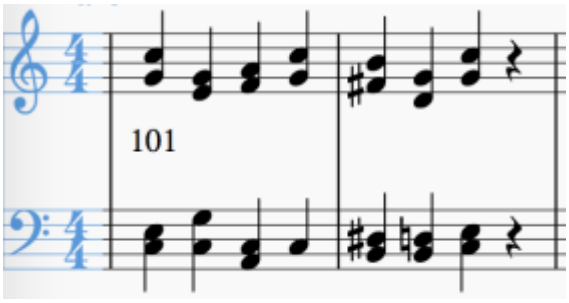
96. 

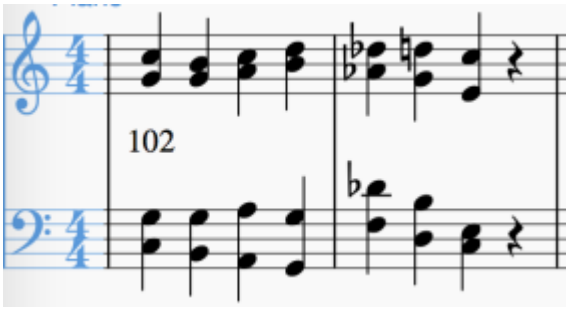
97. 

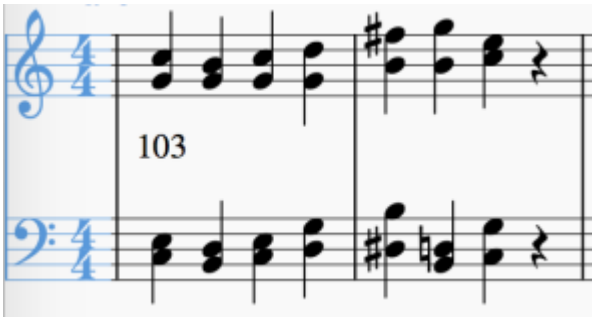
98. 

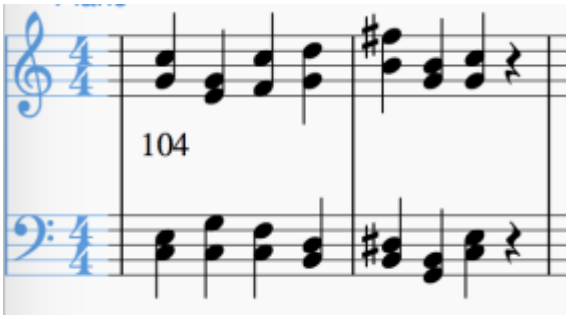
99. 

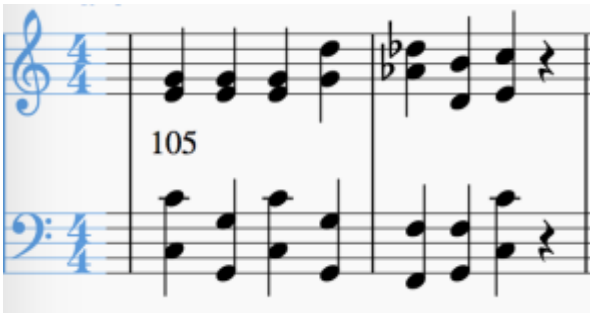
100. 

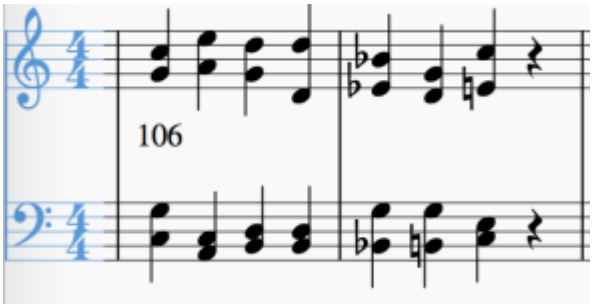
101. 

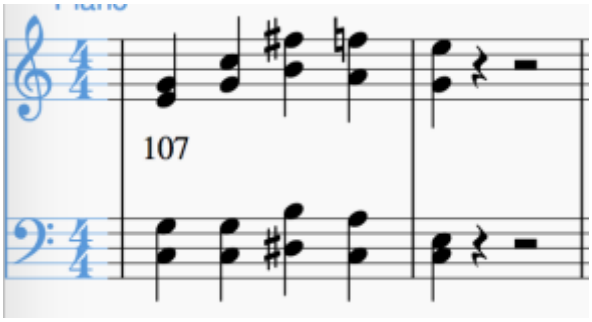
102. 

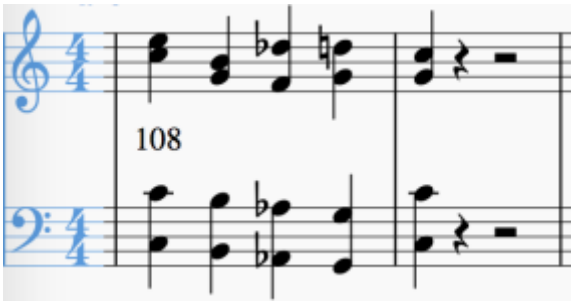
103. 

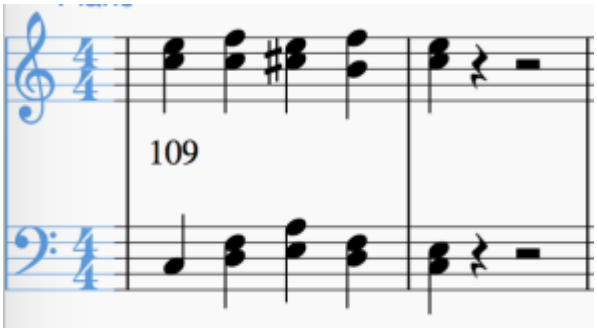
104. 

105. 

106. 

107. 

108. 

109. 

110.