

A Music Theory Ontology

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ABSTRACT

Many existing music ontologies have focused on expressing meta-data related to performances or recordings, aiding with recommendations of songs or artists, and studying the psychological affects of music. These music ontologies provide a foundation for describing many practical aspects related to music. We believe further primitives are needed in order to represent written music and provide a foundation for performing analysis of music. We are motivated by questions related to analyzing music that might inform composers or musicians. Informational elements may include possible underlying chords from a set of notes, as well as summaries of key signatures or scales used in a given song. In order to leverage Semantic Web technologies to answer such questions, we present our Music Theory Ontology that expands on existing work by including theoretical concepts that were absent from previous music ontologies. We further describe a methodology for using the ontology to infer new knowledge. We demonstrate this capability by inferring the notes in various scales and chords, and evaluate the ontology in terms of competency question answering.

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1 INTRODUCTION

The Semantic Web allows for the structuring and annotation of concepts in the form of ontologies, formal representations for concepts in a domain. Our domain of interest is music theory, which focuses on the guiding principles of music, including notation, composition, and analysis. Many of the notations and elements of music theory form natural hierarchies that are interconnected, allowing for the formalization of the theory into an ontology. As discussed in Section 2, existing music ontologies focus on the production or recommendation of music, music therapy or psychology [16, 28, 37] rather than music theory itself, and lack many of the fundamental concepts used for the analysis of music.

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1.1 Namespace Prefixes

In order to describe concepts in our ontology and related ontologies, we reference several namespace prefixes. The ontologies and their corresponding namespaces mentioned are listed in Table 1.

1.2 Music Theory Ontology

In this paper we describe our Music Theory Ontology¹. While there are a variety of representations for music on the global stage, we limit our focus to Western music concepts. Furthermore, we do not touch upon music history, and instead focus on the rudiments necessary for the understanding and analysis of music.

We include classes for musical notation, such as accidentals or time signatures; duration, describing how long a note is or is not played; intervals, representing tonal difference between pitches; and progressions, which involve the succession of notes or chords. Classes are hierarchically organized in terms of subsumption using *rdfs:subClassOf*. We include the *rdfs:label* and *rdfs:comment* annotation properties for every class and property in the ontology. In the case of multiple associated labels to a given class, or as a pointer to shorthand notation, we provide *skos:altLabel* annotations.

The domain and range can be assigned using the *rdfs:domain* and *rdfs:range* predicates, respectively. The properties vary with their domain and range specifications, and sometimes a domain or range are not specified. This is intentional as we want to enable wide reuse and do not want to over constrain a range or a domain unnecessarily. If needed, further restrictions can be added through the application using the ontology.

1.3 Motivation

One motivating factor in designing our Music Theory Ontology is to improve accessibility to fundamental music knowledge for people wishing to learn or improve their understanding of music theory. Due to educational budget cuts, music programs in many schools have been reduced in scope or eliminated altogether [36]. An earlier study found that only a third of examined schools that offered music programs required that their students take a music class [1]. It is noted in a recent study that minimal music education is being provided for students in elementary schools [29]. In the future, we wish to reach people who want to learn music by creating a service that leverages the Music Theory Ontology to help find, propose additions, or mark annotations to musical compositions.

Another potential use case for this ontology includes music analysis. The analysis of the structure of musical compositions can also aid in tasks involving music retrieval or recommendation. Our ontology is designed to help with the understanding of which notes are included in different keys, scales and chords, as well as which

¹Available on <https://archive.org/services/purl/purl/ontology/mt/>

Table 1: Namespace Prefixes and IRIs for Relevant Ontologies

Ontology	Prefix	IRI
<i>General Purpose Ontologies</i>		
Web Ontology Language	owl	<http://www.w3.org/2002/07/owl#>
Resource Description Framework	rdf	<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
RDF Schema	rdfs	<http://www.w3.org/2000/01/rdf-schema#>
XML Schema Datatypes	xsd	<http://www.w3.org/2001/XMLSchema#>
Semanticscience Integrated Ontology	sio	<http://semanticscience.org/resource/>
Units of Measurement Ontology	uo	<http://purl.obolibrary.org/obo/UO_>
Simple Knowledge Organization System	skos	<http://www.w3.org/2004/02/skos/core#>
Dublin Core Terms [35]	dct	<http://purl.org/dc/terms/>
Timeline Ontology [20]	tl	<http://purl.org/NET/c4dm/timeline.owl#>
Time Ontology [13]	time	<http://www.w3.org/2006/time#>
Event Ontology [21]	event	<http://purl.org/NET/c4dm/event.owl#>
<i>Music Related Ontologies</i>		
Music Ontology [22]	mo	<http://purl.org/ontology/mo/>
Chord Ontology [32]	chord	<http://purl.org/ontology/chord/>
Music Theory Ontology	mto	<http://purl.org/ontology/mto/>
Music Theory Ontology Knowledge Base	mto-kb	<http://purl.org/ontology/mto/kb/>
Temperament Ontology [34]	tm	<http://purl.org/ontology/temperament/>
MusicNote [4]	mn	<http://cedric.cnam.fr/isid/ontologies/MusicNote.owl#>

chords comprise progressions. This is useful both in terms of general practice of fundamentals, as well as the learning of patterns in existing music, providing an aid to musicians wishing to learn or recompose a song. This work also has impact in terms of rudimentary understanding of music, aiding with both theoretical analysis of existing work and the creation of new musical compositions.

1.4 Contributions

Our main contribution for this paper is our Music Theory Ontology, which expands on existing work by including theoretical concepts that were absent from previous music ontologies. We describe a methodology for inferring new knowledge by leveraging the concepts and properties in the ontologies. We demonstrate this capability by inferring the notes in various scales and chords. Finally, we include an evaluation of this inference approach, a discussion related to the expressivity of the ontology, and an evaluation of the ontology in terms of competency question answering.

2 RELATED WORK

Increasing interest in using semantic technologies to formally represent musical concepts has resulted in the creation of several ontologies over the past decade. In this section we describe the existing literature related to the semantic representation of music, including ontologies, approaches, and applications.

2.1 Foundational and Theoretical Work

2.1.1 Foundation. The Music Ontology [22] builds on the Timeline Ontology [20], for its time interval and instance concepts; The Event Ontology [21], to describe physical events that occur; the Functional Requirements for Bibliographic Records (FRBR) ontology, for concepts such as Work; as well as, the Friend of a Friend

(FOAF) ontology, for social network descriptions. Using this foundation, The Music Ontology introduces music production specific concepts, such as Record, Track, MusicalWork, Score, Composition, and MusicalManifestation.

2.1.2 Theory. While The Music Ontology provides concepts for modeling performances or relationships between musicians and their songs, necessary concepts to describe rudimentary theory is missing. In order to represent further theoretical aspects of music, we expand by including concepts for music notation, note and rest duration, and by specifying subclasses for intervals, chords, and progressions.

One of the building blocks of The Music Ontology is The Timeline Ontology, which includes concepts necessary for representing temporal information. This allows for the possible approach of representing the content of sheet music as discrete events on a timeline. Some recent work in this regard includes The Segment Ontology, which allows for the division of songs into segments that can be represented on a timeline [7].

Additional theoretical work includes The Chord Ontology [32], which can be used to describe the properties of chords and their notes by adapting a symbolic representation for musical chords [11]. We build on this work by using this symbolic representation to resolve notes in different types of chords. We map the Chord and Interval concepts in our ontology to their corresponding concepts in The Chord Ontology using *owl:equivalentClass*, with the future goal of using The Chord Ontology model to infer inversions for chords. Our Music Theory Ontology can therefore be used to connect the Chord within a unified theoretical framework.

2.2 Music Annotation

The Music Encoding Initiative (MEI) is an effort to define a machine-readable system for encoding musical documents [5]. This is achieved

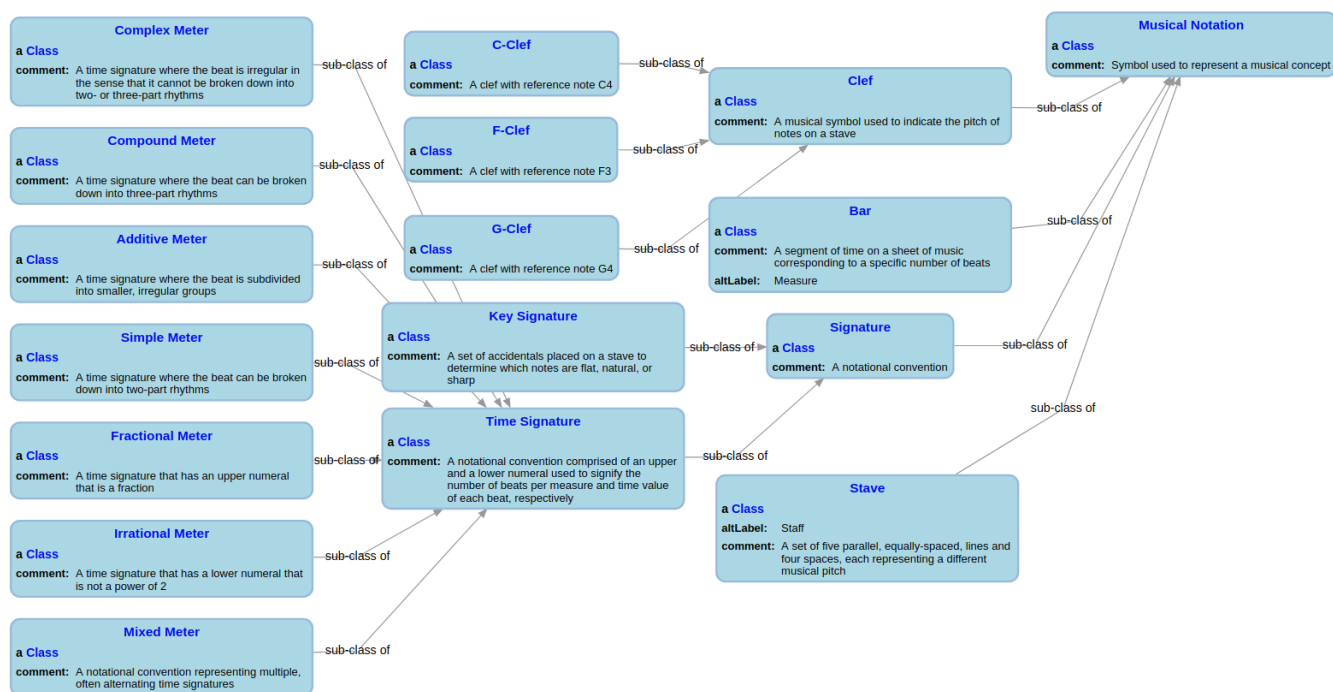


Figure 1: Hierarchy of Musical Notation concepts in our Music Theory Ontology

through a community collaboration between technologists, theorists, and historians. While MEI is based on the eXtensible Markup Language (XML), it does not use Resource Description Framework (RDF) syntax. Using RDF instead of XML restricts the number of possible predicates included in the knowledge schema, and allows for graph-based querying, such as with the use of SPARQL.

Existing ontology-based work that can be leveraged for the annotation of musical scores includes the music notation ontology, MusicNote, which contains classes for representing chords, musical events, and voicing [4]. The authors of this ontology use SWRL [14] rules to detect types of dissonance, including suspension and anticipation, as well as passing, neighbor, and escape notes. This work will aid our future goal of semantically representing and annotating sheet music in order to perform complex musical analysis.

2.3 Music Data Interlinking

In response to a shortage of music metadata standardizations at the time, the MusicBrainz project arose as one of the first Semantic Web based web services that collects metadata about music to make it publicly accessible in Resource Description Framework (RDF) serialization [33]. The system leverages existing ontologies such as terminology from the Dublin Core [35], to, for example, provide annotations for the title or creator of an album.

As information in MusicBrainz is contributed from the users of the system, a relatively recent survey on socio-cultural importance of music metadata aimed to discover why people contribute [12]. Possible conclusions derived from the study include that users are motivated to contribute due to a sense of community obligation as well as the desire to share musical knowledge.

Research stemming from the MusicBrainz project includes the LinkedBrainz project [15], which aims to map the Next Generation Schema (NGS) format adopted by the MusicBrainz project to RDF. Additional goals of this project include incorporating Resource Description Framework in Attributes (RDFa) embeddings and providing a SPARQL endpoint for querying data in the MusicBrainz database.

While there are many databases on the web that contain musical metadata, each of the related systems tend to use its own identifiers, data formats and APIs, making the task of interlinking music related data challenging [23]. Naive interlinking approaches include simple and extended literal look-ups, while more advanced methods use similarity metrics that leverage graph matching [24]. Another approach includes mapping folksonomies to ontologies to leverage folksonomy-based system operations [19].

2.4 Music Recommendation and Retrieval

Data interlinking approaches can be applied to aid in music recommendation and retrieval. Early applications using Semantic Web technologies to aid in context-based representations of music for retrieval include the MX-Onto ontology, which includes concepts for ensembles, dance types, genre classification, and form [6], and the “Foafing the Music” system. Using the Friend of a Friend (FOAF) ontology and the RDF Site Summary (RSS) metadata description format to aid in user profiling, along with extracted context based information from RSS feeds, such as recent song releases, this system is able to provide music recommendations to users [3].

More recent attempts at ontology-based music recommendation include the Context-based Music Recommendation (COMUS) ontology [26, 31], which builds on The Music Ontology and appends concepts to aid the expression of musical situations and mood, such as pitch, duration, tempo and rhythm. Some challenges associated with context-based recommendation for music relate to music feature extraction and classification, human emotion prediction, and establishing connections among ontology based representations [10].

Other applications, including MuzkMesh [30] and MusicPedia [18], take advantage of Application Programming Interface (API) calls to existing music data web services such as MusicBrainz or Last.fm².

While the ontologies described above have numerous applications, one aspect missing from existing work is the inclusion of many theoretical concepts, including scales and progressions. Scales and progressions are key elements in analyzing music and provide a foundation for enhanced musical comparisons.

3 INFORMATION ARCHITECTURE






3.1 Musical Notation




Sheet music is generally written on one or multiple staves, which is a set of five parallel, equally-spaced, lines where each of the lines and the spaces between them represent a different musical pitch. In order to indicate which pitch or note should be played for each line or space, a clef is specified at the beginning of a musical part.

Also indicated at the beginning of a musical part are the time signature and the key signature. The time signature comprises an upper and a lower numeral used to signify the number of beats per bar and time value of each beat, respectively. We include several classes of time signatures, including simple, compound, complex, additive and irrational meters.

The key signature is used to represent the set of accidentals placed on a staff, usually signifying which key the song or part should be played in. An accidental is a notational symbol that determines a change in pitch of a note, the most common being flats, naturals, and sharps. A flat lowers a note by a semitone, a sharp raises a note by a semitone, and a natural brings a note from an altered tone back to its original pitch.

We include the class MusicalNotation in our ontology with the goal that it will help in the future task of being able to semantically represent sheet music. Several classes defined to represent musical notation, such as clefs, times signatures, and accidentals, including double flats and sharps, as listed below.











- Musical Notation
 - Stave
 - Bar
 - Clef
 - * G-Clef 
 - * F-Clef 
 - * C-Clef 
 - Accidental
 - * Flat 
 - * Natural 

- * Sharp 
- * Double Flat 
- * Double Sharp 
- Signature
 - * Time Signature
 - Simple Meter $\frac{4}{4}$ (or **C**), $\frac{3}{4}$
 - Compound Meter $\frac{5}{4}$
 - Complex Meter $\frac{7}{8}$
 - Additive Meter $2 + \frac{3}{8} + 2$
 - Irrational Meter $\frac{22}{7}$
 - * Key Signature

A subset of our Music Theory Ontology that corresponds to music notation is depicted in Figure 1.

3.2 Duration

In order to represent how long a note should be played, varying notational symbols are used. Additionally, a set of symbols are used to signify the amount of time that no note should be played, referred to as rests. Therefore, we include a concept for duration in our ontology, several classes of which are listed below. The corresponding symbols for the notes and rests are also provided.

- Duration
 - Note Duration
 - * Semibreve (Whole Note) 
 - * Minum (Half Note) 
 - * Crotchet (Quarter Note) 
 - * Quaver (Eighth Note) 
 - * Semiquaver (Sixteenth Note) 
 - Rest
 - * Semibreve Rest (Whole Rest) 
 - * Minum Rest (Half Rest) 
 - * Crotchet Rest (Quarter Rest) 
 - * Quaver Rest (Eighth Rest) 
 - * Semiquaver Rest (Sixteenth Rest) 

One future task is to assign the corresponding notational symbols to each duration class, with the goal of being able to process sheet music and map the parts to the corresponding classes. Furthermore, as the duration of the musical symbols can be modified through musical notation dots and ties, future work includes the ability to represent these kinds of modifications.

3.3 Interval

In music theory, it is important to be able to represent the tonal difference between two pitches, often referred to as an interval. We focus on perfect, major, minor, augmented and diminished intervals. We also consider both diatonic intervals, where the first and last note are part of the same major scale, and chromatic intervals, where the first and last note are not. Furthermore, we include harmonic intervals, which occur when multiple notes are played simultaneously, forming chords, as further discussed in section 3.4. When notes are played in sequence, they are referred to as melodic intervals. Several classes of intervals are listed below. While we only list restrictions for perfect and major intervals below, the appropriate subclasses of minor, augmented, and diminished intervals are included in the ontology.

²<https://www.last.fm/>

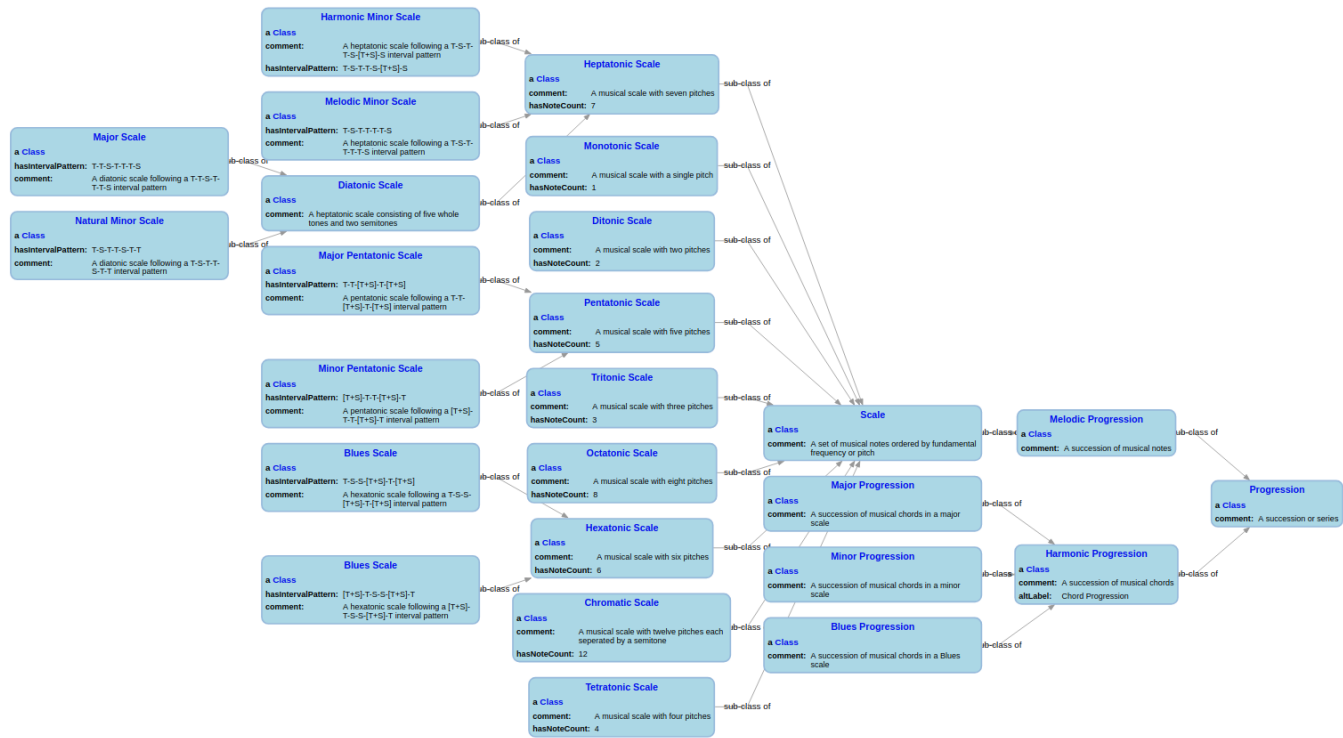


Figure 2: Hierarchy of Progression concepts in our Music Theory Ontology

- Interval
 - Diatonic Interval
 - Chromatic Interval
 - Perfect Interval
 - * Perfect Unison
 - * Perfect Fourth
 - * Perfect Fifth
 - * Perfect Octave
 - Major Interval
 - * Major Second
 - * Major Third
 - * Major Sixth
 - * Major Seventh
 - Minor Interval
 - Augmented Interval
 - Diminished Interval
- Harmonic Interval
 - Chord
- Melodic Interval

In order to leverage terminologies in existing ontologies, we first considered aligning `mto:Interval` with a concept of the same name defined in The Timeline Ontology. However, The Timeline Ontology class `tl:Interval` builds on `ProperInterval` from The Time Ontology [13], which is defined as a temporal entity. The interval that we refer to in our ontology represents a difference in pitch rather than time. Therefore, a more appropriate mapping is the `chord:Interval` class defined in the Chord Ontology, which is designed to represent tonal distance from the root. We map `mto:Interval`

in our ontology to `chord:Interval` using the `owl:equivalentClass` property.

3.4 Chord

When any harmonic set of pitches consisting of two or more notes are sounded simultaneously, a chord is formed. A chord consisting of a root note, a note a major third above the root, and a note a perfect fifth above the root forms a major triad. When a minor third replaces the major third, a minor triad is produced. When the fifth of the major triad is augmented by a semitone, an augmented triad is produced. When the fifth of a minor chord is lowered by a semitone, a diminished triad is produced. We also consider classes of chords that are named for the number of notes in the chord, such as a single note monad, a triad with three notes, or a decad with ten. Several classes for chords in our Music Theory Ontology are listed below.

- Harmonic Interval
 - Chord
 - * Monad
 - * Dyad
 - * Triad
 - Major Triad
 - Minor Triad
 - Augmented Triad
 - Diminished Triad
 - * Tetrad
 - Sixth Tetrad
 - Seventh Tetrad

- * Pentad
 - Ninth Pentad
- * Decad

The Chord Ontology [32] defines a Chord class for conveying chords and their properties in terms of the root and base notes, as well as additional notes at intervals of various degrees. In order to leverage these properties, we align our Chord class with the Chord ontology using *owl:equivalentClass*.

3.5 Progression

In order to analyze pieces of music, it is important to be able to classify sequences of notes or chords, which in music theory are referred to as progressions. A succession of musical chords results in a harmonic progression, the most common being major, minor and blues progressions. Future work includes the ability to detect and codify progressions from sheet music. A succession of musical notes is referred to as a melodic progression. An important category of melodic progressions are scales, which are sets of musical notes ordered by pitch. Classes of scales are usually separated by the number of notes in the scale, including chromatic scales, which have twelve notes, each separated by a semitone, heptatonic scales which have seven notes, and hexatonic scales which have six.

- Scale
 - Chromatic Scale
 - Heptatonic Scale
 - * Diatonic Scale
 - Major Scale
 - Natural Minor Scale
 - Harmonic Minor Scale
 - Melodic Minor Scale
 - Hexatonic Scale
 - * Major Blues Scale
 - * Minor Blues Scale
 - Pentatonic Scale

A subset of our Music Theory Ontology that corresponds to progression concepts is depicted in Figure 2.

3.6 Degree

The position of a particular note in a scale is referred to as its degree. We consider the named degrees of notes in diatonic scales. For such scales, the first note is referred to as the tonic note, the third note is referred to as the mediant, the fifth the dominant. Similarly, all diatonic degrees are named.

In order to represent degrees for scales that do not have exactly seven notes, we also represent degrees numerically as semitone integer distances relative to the previous note in the scale. We define the properties *mto:hasNote* to associate a note to a scale or chord, and *mto:hasDegree* to assign a degree value to a note.

4 METHODOLOGY

4.1 Ontology Engineering

In order to engineer our Music Theory Ontology, we took a competency question approach by considering limitations in the existing music ontologies and thinking of questions that we want The

Table 2: Dictionary Mapping to frequency and wavelength to notes

Column	Attribute	attributeOf	Unit	Entity
Note				mto:Note
Octave	mto:RelativeOctave	Note		
Frequency	sio:Frequency	Note	uo:0000106	
Wavelength	mto:Wavelength	Note	uo:0000008	

Music Theory Ontology to be able to answer. Several competency questions include:

- Given a single note, what are the remaining notes in a chord that contains that note?
- What key signatures or scales are used throughout a song?
- What chords are present in a given progression?
- Given any note in a scale and its degree, can we determine the other notes in the scale?

While we focus on competency questions in this paper, future considerations may include modeling questions, such as:

- How can existing musical works be theoretically analyzed?
- How can the notes that occur in the song, chords built from the notes, or progressions that those chords follow be modeled?

With these kinds of questions in mind, we decided that it would be important to include concepts for musical notation, duration, intervals, chords and progressions.

4.2 Semantic Data Dictionary Assertions

In order to demonstrate the applicability of our Music Theory Ontology, we decided to use the Semantic Data Dictionary (SDD) approach [25] to make assertions for diatonic scales, frequencies associated with notes, and the numbers of flats or sharps in given key signatures. The SDD can be used to annotate the schema structured data tables with concepts from ontologies and create a graphical representation. In the SDD Dictionary Mapping table, we assert the relationship *Scale mto:hasTonic Note*. The SDD Dictionary Mapping table for mapping the frequency and wavelength to each note is provided in Table 2. The concepts *mto:RelativeOctave*, *sio:Frequency*, and *mto:Wavelength* are asserted as attributes of *mto:Note*. Corresponding notes and scales from the ontology are mapped directly using the SDD Codebook. Using this approach, RDF knowledge assertions were generated.

Since the “Note” column from each of the SDDs are both encoded as *mto:Note*, the individual assertions can be aligned, allowing the inference of the frequency for a given note in a scale.

4.3 Deductive Inferencing

4.3.1 Scale Degree Inference. In order to test the applicability of the ontology, we wrote several deductive inference agents using the Whyis framework [17]. Our initial scope was to infer the remaining notes in a diatonic scale, given the tonic note and the interval pattern of the scale. The interval pattern is encoded in the ontology as a property *mto:hasIntervalPattern* of the *mto:Scale* class, and is later parsed by the inference agent. We then generalized the algorithm to infer the notes in scales with arbitrary numbers of

degrees, and, in addition to diatonic scales, applied this approach to infer pentatonic and hexatonic scales. The algorithm approach begins by querying for the scale and tonic note instances asserted from the SDD approach, and the interval pattern from the related scale class in the ontology. The interval pattern is then parsed to determine interval lengths in terms of semitone counts, where “S” for semitone corresponds to 1, “T” for tone corresponds to 2, and “TT” for tritone corresponds to 6 semitone distances. Additive intervals such as “T+S” are also supported. Once these intervals are converted into integers, starting from the position of the tonic note in the chromatic scale,³ by incrementing the position of the previous note, the position of the current note in the chromatic scale can be determined. The set of inferred degree notes for scales with a tonic of “A” is shown in Table 3.

4.3.2 Chord Degree Inference. Expanding on this approach, we were able to infer chord degree notes by using the symbolic notation for the components in a chord described in [11]. The property *mto:hasComponentsList* of the *mto:Chord* class is used to encode chord components lists, allowing for parsing of the chord components by the inference agent. Similar to the approach with scales, integral semitone distances are determined from the components list. However, one key difference in the inference agent algorithms is that rather than incrementing the position of the previous note, the position of the root note is recorded and then incremented at each step. The set of inferred degree notes for chords with a tonic of “A” is shown in Table 4, which contains the types of chords for which degree notes we have inferred.

One assumption taken in this inference approach was that the notes in the scales and chords exist in the chromatic scale, as is the case for most classical and contemporary Western music. Although in Tables 3 and 4 we have shown the results for a single tonic, we are able to perform these inference activities using any note from the chromatic scale as the root.

5 EVALUATION

5.1 Inference Evaluation

In terms of inferring notes in scales, we are able to derive degrees for 4 diatonic scales, the Major and Natural, Melodic and Harmonic Minor scales; 2 hexatonic scales such as Major and Minor Blues scales; and the 2 pentatonic Major and Minor scales. For these 8 scales we are able to derive $(4 \times 7) + (2 \times 6) + (2 \times 5) = 50$ additional degree values. Therefore, considering each of the 12 notes in the chromatic scale that serve as the tonic note for each set of scales, we are able to infer a total of $50 \times 12 = 600$ scale degree notes.

In terms of inferring notes in chords, for each of the 12 notes in the chromatic scale, we are able to derive 48 additional chord degrees by leveraging the component lists for 17 chord classes, resulting in a total of $12 \times 48 = 576$ chord degree notes inferred.

5.2 Ontology Expressivity

By loading our Music Theory Ontology into Protégé, we are able to observe several ontology metrics [8]. The current version of the ontology includes 160 classes, 10 object type properties, and 10 datatype properties, with a maximum subsumption depth of 5.

³Chromatic Scale = {C C♯/D♭ D D♯/E♭ E F F♯/G♭ G G♯/A♭ A A♯/B♭ B}

Many axioms are incorporated within these classes and properties, including 333 logical, 180 declaration, 216 class, 16 object property, 15 datatype property, and 480 annotation axioms.

The Description Logic (DL) expressivity of the ontology is *ALHO(D)*, where *AL* represents an attributive language, which supports atomic negation, concept intersection, universal restrictions and limited existential quantification. The *H* denotes the use of role hierarchies, *O* includes the use of nominals, and *(D)* signifies that the ontology uses data values, datatypes, or datatype properties.

5.3 Ontology Evaluation

We evaluate our Music Theory Ontology in terms of ability to answer a set of relevant competency questions. For questions that we are currently unable to answer with our ontology, we discuss future research directions.

Given a single note, what are the remaining notes in a scale? If we are given the tonic note of a scale, we can determine the remaining notes in the scale. Using a variation of this same approach, given any note and the degree of the note in the scale, we can determine the remaining notes.

Given the tonic note, what are the remaining notes in a chord? We are able to resolve the notes in many types of chords, including major, minor, augmented, diminished, suspended, sixth, seventh, and ninth chords. Future work includes expansion of supported chord types and the ability to resolve chord inversions.

What chords are present in a given progression? Following a similar methodology to the inference approach for scales and chords, the inference of chords in a progression is possible. Initial proof of concept work to this end has been promising, where we are able to determine the root note and types of chords that are present in the progression. Nevertheless, in order to allow for even more chords to be expressed, future work includes incorporating currently missing support for chord inversions.

Do a set of notes comprise a phrase? While currently not supported, future work involves including phrase related concepts.

Does a progression of chords result in a cadence? We currently do not have concepts or axioms related specifically to cadence, although some may be included in the future.

For a given key signature, what notes are flat or sharp? Key signature classes in the ontology have properties denoting the number of flats or sharps that are in the signature. It is possible to use these counts to determine which notes are flat or sharp.

Can the elements of a composition be modeled semantically? We have designed this ontology with compositional music elements in mind, allowing for the annotations of notes, clefs, accidentals, signatures, note durations, and rests. Using these concepts, many elements of a composition can be modeled. Further composition modeling will be possible in the future, as extension work involves the inclusion of concepts for modeling dynamics.

Can existing music be analyzed theoretically? While we have incorporated many music theory concepts and have demonstrated how to apply inference, we have yet to apply this methodology to existing music. One future goal is to parse MusicXML [9], available through applications like MuseScore [2], and provide additional annotations of inferred scales, chords and progressions.

Table 3: Inferred scale degree notes given the tonic note and scale type

Tonic	Scale Type	Interval Pattern	Degree							
			1st	2nd	3rd	4th	5th	6th	7th	8th
A	Harmonic Minor Scale	T-S-T-T-S-[T+S]-S	A	B	C	D	E	F	G \sharp / A \flat	A
A	Major Blues Scale	T-S-S-[T+S]-T-[T+S]	A	B	C	C \sharp / D \flat	E	F \sharp / G \flat	A	
A	Major Pentatonic Scale	T-T-[T+S]-T-[T+S]	A	B	C \sharp / D \flat	E	F \sharp / G \flat	A		
A	Major Scale	T-T-S-T-T-T-S	A	B	C \sharp / D \flat	D	E	F \sharp / G \flat	G \sharp / A \flat	A
A	Melodic Minor Scale	T-S-T-T-T-T-S	A	B	C	D	E	F \sharp / G \flat	G \sharp / A \flat	A
A	Minor Blues Scale	[T+S]-T-S-S-[T+S]-T	A	C	D	D \sharp / E \flat	E	G	A	
A	Minor Pentatonic Scale	[T+S]-T-T-[T+S]-T	A	C	D	E	G	A		
A	Natural Minor Scale	T-S-T-T-S-T-T	A	B	C	D	E	F	G	A

Table 4: Inferred chord degree notes given the tonic note and chord type

Tonic	Chord Type	Components List	Degree				
			1st	2nd	3rd	4th	5th
A	Augmented Chord	3, \sharp 5	A	C \sharp / D \flat	F		
A	Diminished Chord	\flat 3, \flat 5	A	C	D \sharp / E \flat		
A	Diminished Seventh Chord	\flat 3, \flat 5, \flat 7	A	C	D \sharp / E \flat	F \sharp / G \flat	
A	Dominant Ninth Chord	3, 5, \flat 7, 9	A	C \sharp / D \flat	E	G	A \sharp / B \flat
A	Dominant Seventh Chord	3, 5, \flat 7	A	C \sharp / D \flat	E	G	
A	Half Diminished Seventh Chord	\flat 3, \flat 5, \flat 7	A	C	D \sharp / E \flat	G	
A	Major Chord	3, 5	A	C \sharp / D \flat	E		
A	Major Ninth Chord	3, 5, 7, 9	A	C \sharp / D \flat	E	G \sharp / A \flat	A \sharp / B \flat
A	Major Seventh Chord	3, 5, 7	A	C \sharp / D \flat	E	G \sharp / A \flat	
A	Major Sixth Chord	3, 5, 6	A	C \sharp / D \flat	E	F \sharp / G \flat	
A	Minor (Major Seventh) Chord	\flat 3, 5, 7	A	C	E	G \sharp / A \flat	
A	Minor Chord	\flat 3, 5	A	C	E		
A	Minor Ninth Chord	\flat 3, 5, \flat 7, 9	A	C	E	G	A \sharp / B \flat
A	Minor Seventh Chord	\flat 3, 5, \flat 7	A	C	E	G	
A	Minor Sixth Chord	\flat 3, 5, 6	A	C	E	F \sharp / G \flat	
A	Suspended Fourth Chord	4, 5	A	D	E		
A	Suspended Second Chord	2, 5	A	B	E		

6 DISCUSSION & FUTURE WORK

Despite covering many important concepts, the coverage in our ontology is incomplete in a number of dimensions. A future goal is the inclusion of additional concepts into the ontology, including dynamics, such as forte to represent a loudly played note or pianissimo for very soft; mode, where a scale may not start on the tonic note, such as Dorian or Lydian; as well as consonance and dissonance, which represent qualities of intervals or sequential notes. Additional extensions may include rhythm and melody concepts, historical elements, or genres, such as Classical, Blues or Jazz.

Another future goal is to implement the ability to semantically represent sheet music in order to discover patterns, such as intervals or progressions. The association of notation symbols to concepts, such as clefs, accidentals, notes and rests, will aid in the interpretation of existing musical works. This will be done in conjunction with existing ontologies which describe symbolic music, and applications like MuseScore. We will deploy the ontology in tooling for ‘semantic music,’ such as that being developed in the Fusing Audio and Semantic Technologies (FAST) project in the UK.

An additional future application may include analyzing algorithm-generated compositions, such as from Numbers Into Notes [27]. We hope that our knowledge representation will help the Semantic Web community engage with music and musical applications.

7 CONCLUSION

In this paper, we present our Music Theory Ontology. We describe related literature, present our information architecture, and provide a methodology for inference of new knowledge. We demonstrate this capability by inferring the notes in scales and chords. We include evaluations of both the inference approach and the ontology, and discuss future extensions. This work will improve the accessibility of theoretic music information, and aid with both the learning and analysis of music. In the future, we plan to apply this work to tasks involving music analysis, education, and retrieval.

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