2d International Meeting of the Society for Mathematics and Computation in Music

&

John Clough Memorial Conference

June 19–22, 2009
Yale University

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Summary Schedule of Sessions and Events

Friday June 19

1:00–2:00	*Registration (Whitney Humanities Center = WHC)*
2:00–5:00	*Paper Session 1: Composition, Voice-Leading, Atonality (WHC Auditorium)*
5:30–6:45	*Conference Welcome and Keynote Lecture (Beinecke)*
6:45–8:00	*Reception (Beinecke)*

Saturday June 20

9:00–10:00	*Coffee/breakfast (WHC 108)*
10:00–12:00	*Paper Session 2: Geometry (WHC Auditorium)*
12:00–1:30	*Lunch (WHC 108)*
1:30–3:30	*Paper Session 3: Scale (WHC Auditorium)*
3:30–4:00	*Light afternoon reception (WHC 108)*
4:00–6:00	*Poster Session (WHC 208 & Rotunda)*
6:00–7:30	*Dinner on your own (SMCM officers meet over dinner)*
7:30–9:00	*JMM Editorial board meeting (Stoeckel 107)*

Sunday June 21

8:00–9:00	*Coffee/breakfast (WHC 108)*
9:00–12:00	*Tutorials (WHC & Stoeckel)*
12:00–1:00	*Lunch (WHC Rotunda)*
1:00–2:00	*General business meeting (WHC Auditorium)*
2:00–3:30	*Paper Session 4: Perception (WHC Auditorium)*
3:30–4:00	*Light afternoon reception (WHC 108)*
4:00–5:30	*Paper Session 5: Time (WHC Auditorium)*
5:30–7:30	*Dinner on your own*
7:30–9:00	*Panel (WHC Auditorium)*

Monday June 22

8:00–9:00	*Coffee/breakfast (WHC 108)*
9:00–12:00	*Paper Session 6: New Interdisciplinary Approaches (WHC Auditorium)*

A map of the Yale campus may be found in the center of this booklet.

Registration will be held 1:00–2:00
in the Whitney Humanities Center

Paper Session 1, 2:00 – 5:00
Whitney Humanities Center, Auditorium

Composition, Voice-Leading, Atonality

Musical Experiences with Block Designs

Franck Jedrzejewski, Commissariat à l'Énergie Atomique-
Institut National des Sciences & Techniques Nucléaires
Moreno Andreatta, IRCAM, CNRS
Tom Johnson, Paris

Since the pioneer works of composer Tom Johnson, many questions arise about block designs. The aim of this paper is to propose some new graphical representations suitable for composers and analysts, and to study the relationship between pcsets and small *t*-designs. After a short introduction on the combinatorial aspects of *t*-designs, we emphasize the musical perspectives open by these mathematical objects.

Generalized Voice Exchange

Robert Peck, Louisiana State University

The notion of voice exchange in ordered pitch-class space conforms closely to that of contextual inversion in neo-Riemannian theory: the melodic dyad (*a*, *b*) in one voice inverts in another voice, and we define an axis of inversion respectively for all such pairs. We may thus apply many of the transformational concepts of neo-Riemannian theory to a study of voice exchange. We draw our musical examples from the Prelude to Richard Wagner's *Tristan und Isolde*, for which a separate analytical thread exists that considers aspects of tonality in relation to the voice exchange in the resolution of the Tristan Chord.

Maximally Smooth Diatonic Trichord Cycles

Steven Cannon

In the usual seven-note diatonic scale, the maximally smooth cycle of triads contains a long section that uses only major and minor triads, the same triad that forms maximally smooth cycles within the twelve-note chromatic scale. Tonal music exploits this property of the scale to create sequences of similar chords. The goal of this study is to determine the extent to which such long chains containing inversionally related species exist in maximally smooth trichord cycles within microtonal scale systems that share certain properties with the diatonic. The study thus combines neo-Riemannian theory, especially Cohn's concept of maximally smooth cycles, with the diatonic scale theory developed by Clough and other authors. The patterns of maximally smooth trichord cycles depend on the type of scale within which they occur, and on the cardinalities of the scales. Among all scales, the usual diatonic supports the longest possible chain.

The Continuous Hexachordal Theorem

Brad Ballinger, Davis School for Independent Study
Nadia Benbernou, Massachusetts Institute of Technology
Francisco Gomez, Universidad Politecnica de Madrid
Joseph O'Rourke, Smith College
Godfried Toussaint, McGill University

The Hexachordal Theorem may be interpreted in terms of scales, or rhythms, or as abstract mathematics. In terms of scales it claims that the complement of a chord that uses half the pitches of a scale is homometric to — i.e., has the same interval structure as — the original chord. In terms of onsets it claims that the complement of a rhythm with the same number of beats as rests is homometric to the original rhythm. We generalize the theorem in two directions: from points on a discrete circle (the mathematical model encompassing both scales and rhythms) to a continuous domain, and simultaneously from the discrete presence or absence of a pitch/onset to a continuous strength or weight of that pitch/onset. Although this is a significant generalization of the Hexachordal Theorem, having all discrete versions as corollaries, our proof is arguably simpler than some that have appeared in the literature. We also establish the natural analog of what is sometimes known as Patterson's second theorem: if two equal-weight rhythms are homometric, so are their complements.

Sequential Association Rules in Atonal Music

Aline Honingh, City University London
Tillman Weyde, City University London
Darrell Conklin, City University London

This paper describes a preliminary study on the structure of atonal music. In the same way as sequential association rules of chords can be found in tonal music, sequential association rules of pitch class set categories can be found in atonal music. It has been noted before that certain pitch class sets can be grouped into 6 different categories [10]. In this paper we calculate those categories in a different way and show that virtually all possible pitch class sets can be grouped into these categories. Each piece in a corpus of atonal music was segmented at the bar level and of each segment it was calculated to which category it belongs. The percentages of occurrence of the different categories in the corpus were tabulated, and it turns out that these statistics may be useful for distinguishing tonal from atonal music. Furthermore, sequential association rules were sought within the sequence of categories. The category transition matrix shows how many times it happens that one specific category is followed by another. The statistical significance of each progression can be calculated, and we present the significant progressions as sequential association rules for atonal music.

Badness of Serial Fit Revisited

Tuukka Ilomäki, Sibelius Academy

David Lewin introduced the notion of Badness of Serial Fit, or BSF, to analyze the relation between two twelve-tone rows. It is based on Milton Babbitt's idea of the protocol made of the shared ordered pairs of pitch classes of two rows and aims to evaluate how distinctive the protocol is. While BSF has been mentioned several times in the music theory literature, so far little progress has been made in the analysis of its properties. This paper formalizes BSF in terms of partial orders and links the musical discourse to the pertinent literature in mathematics and computer science. BSF is analyzed in terms of computational complexity and it is shown to be related to the notion of "presortedness" used in the analysis of sorting algorithms. It is proven that the logarithms of the values of BSF define a metric for twelve-tone rows. This new metric is several orders of magnitude finer than any other measure discussed in the literature.

Conference Opening and Keynote Lecture, 5:30 – 6:45
Beinecke Library, 2d Floor

The End of Pythagoreanism: *Musica theorica*, Natural Science, and Aristotle's Philosophy of Mathematics, c.1300-c.1600

David Cohen, Columbia University

David Cohen is Associate Professor of Music at Columbia University, having taught at Harvard, Tufts, and Brandeis. His research centers on the history of music theory, with a special focus on musical thought in antiquity and its transmission to the Middle Ages and beyond, and on interactions between music theory and philosophy (including aesthetics), science, and the other arts. His article on Aristoteleanism in 14th-century music theory, "The Imperfect Seeks Its Perfection: Harmonic Progression, Directed Motion, and Aristotelian Physics," won the Society for Music Theory's Outstanding Publication Award in 2003.

The Beinecke Library will host a reception on the 2d floor immediately following the keynote lecture.

Coffee & breakfast will be served at 9:00
in room 108 of the Whitney Humanities Center.

Paper Session 2, 10:00 – 12:00
Whitney Humanities Center, Auditorium

Geometry

Hamiltonian Cycles in the Topological Dual of the Tonnetz

Giovanni Albini and Samuele Antonini, University of Pavia

The Hamiltonian cycles in the topological dual of the Tonnetz (i.e. the successions of triads connected only through PLR-transformations which visit every minor and major triad only once) will be introduced, enumerated on, studied, and classified both from a theoretical and analytical point of view.

Pairwise Well-formed Scales and a Bestiary of Animals on the Hexagonal Lattice

Jon Wild, McGill University

Some pitch-class collections may be represented as subsets of a two-dimensional lattice or generalized Tonnetz. Whereas a well-formed scale of cardinality *n* is formed as a simple interval chain, and thus defined unambiguously by the size of its generating interval, there are a great number of inequivalent ways of forming connected n-subsets of the two-dimensional lattice defined by a given pair of basis intervals. Only very few of these connected subsets or lattice animals ever turn out to correspond to collections that possess the pairwise well-formed property. PWWF scales are found to correspond to members of a small family of lattice animals that is independent of the generators at the basis of the lattice. Finally a method is shown for constructing a pair of generators that will yield any given heptatonic PWWF scale; the method is easily extended to other cardinalities.

Three Conceptions of Musical Distance

Dmitri Tymoczko, Princeton University

This paper considers three conceptions of musical distance (or inverse 'similarity') that produce three different musico-geometrical spaces: the first, based on voice leading, yields a collection of continuous quotient spaces or orbifolds; the second, based on acoustics, gives rise to the *Tonnetz* and related 'tuning lattices'; while the third, based on the total interval content of a group of notes, generates a six-dimensional 'quality space' first described by Ian Quinn. I will show that although these three measures are in principle quite distinct, they are in practice surprisingly interrelated. This produces the challenge of determining which model is appropriate to a given music-theoretical circumstance. Since the different models can yield comparable results, unwary theorists could potentially find themselves using one type of structure (such as a tuning lattice) to investigate properties more perspicuously represented by another (for instance, voice-leading relationships).

The Geometry of Melodic, Harmonic, and Metrical Hierarchy

Jason Yust

Music is hierarchically structured in numerous ways, and all of these forms of organization share essential mathematical features. A geometrical construct called the Stasheff polytope or associahedron summarizes these similarities. The Stasheff polytope has a robust mathematical literature behind it demonstrating its wealth of mathematical structure. By recognizing hierarchies that arise in music, we can see how this rich structure is realized in multiple aspects of musical organization. In this paper I define hierarchic forms of melodic, harmonic, and metrical organization in music, drawing on some concepts from Schenkerian analysis, and show how each of them exhibits the geometry of the Stasheff polytope. Because the same mathematical construct is realized in multiple musical parameters, the Stasheff polytope not only describes relationships between hierarchies on a single parameter, but also defines patterns of agreement and conflict between simultaneous hierarchies on different parameters. I give musical examples of conflict between melodic and rhythmic organization, and show how melodic and harmonic organization combine in melody and counterpoint.

Lunch will be served at 12:00 in room 108 of the Whitney Humanities Center.

Paper Session 3, 1:30 – 3:30
Whitney Humanities Center, Auditorium

Scale

Regions and Standard Modes

David Clampitt, Ohio State University
Thomas Noll, Escola Superior de Musica de Catalunya

Norman Carey and David Clampitt observed in [4] that each region has two well-formed scales as its prefixes. If one looks at this finding from the viewpoint of word theory, one observes that regions are central words and the two prefixes are their independent periods. More precisely, each region, understood as a word in a two-letter alphabet, contains two distinct prefixes, both of which represent well-formed scales. One period is a special standard word, and the other period is a non-special standard word. Thomas Noll proposed in [13] to generalize the authentic Ionian mode through special standard words. He showed that the property of divider incidence characterizes these words among their conjugates. Thus there are two parallel lines of generalization which can be further enriched by observations from [7], [8], as well as by further combinatorial connections between central and standard words. Two independent lines of research turn out to have so many conceptual cross-links, that a productive synergy emerges immediately from their contact (see [10], [6], [13], [14]). In the past two decades Norman Carey and David Clampitt developed mathematical music theory for the study of scales, regions and related concepts. At the same time mathematicians such as Aldo de Luca, Jean Berstel, Valérie Berthé, Christian Kassel, and Christophe Reutenauer investigated a certain branch of algebraic combinatorics on two-letter words, which includes the study of central words, standard words, Christoffel words. We refer the reader to chapter 2 in [11], as well as to [3], [12], [1], [2].

Generalized Tonnetz and Well-Formed GTS
A Scale Theory Inspired by the Neo-Riemannians

Marek Žabka, Comenius University

The paper connects two notions originating from different branches of the recent mathematical music theory: the neo-Riemannian *Tonnetz* and the property of well-formedness from the theory of the generated scales. These notions are mathematized and their properties are rigorously investigated. As the

first result, the concepts of the generalized *Tonnetze* and of the multidimensional (i.e. based on multiple generators) generated tone-systems (GTS) are formally defined. Secondly, we prove a theorem stating that a normal two-dimensional GTS is well-formed if and only if it is closed. This is the main mathematical result of the paper and it can be considered a generalization of Carey-Clampitt's work on one-dimensional generated scales to GTS's with two generators. Finally, we illustrate power of the proposed theoretical framework. It covers various theoretical concepts found in different musical contexts. Besides the neo-Riemannian *Tonnetze* and Carey-Clampitt's generated scales, our examples include Mazzola's 'harmonic band,' the pitch helix known from the psychology of hearing, the ancient Chinese system of *lü-lü*, the Arabic 24-*nīm* system, and the ancient Indian 22-*śruti* system. In particular, we give a possible explanation of the number 22 in the Indian system.

Formal Diatonic Intervallic Notation

Jack Douthett, University of New Mexico
Julian Hook, Indiana University

Numbers called *quality modifiers* are used to identify interval qualities: 0 numerically represents perfect, ½ represents major, –½ represents minor, and so on. These modifiers are linked with *diatonic class intervals* as ordered pairs that mimic common interval notation. For example, a minor third is represented by (–½, 2). A binary operator is constructed that allows these ordered pairs to be added consistent with our expectations. Similarly, *accidental modifiers* numerically identify the number of sharps or flats attached to a given note: 0 indicates no attached accidentals, negative integers indicate the number of flats attached, and positive integers indicate the number of sharps attached. These modifiers are linked with *diatonic classes* as ordered pairs that mimic common note names. For example, the note Gb is represented by (–1,4) and Gx by (2,4). Intervals and notes represented by these ordered pairs are said to be in *MD-notation* (MD for *modifier-diatonic*). A group action and generalized interval system are defined for intervals and notes in MD-notation. An implied quarter-tone system is also discussed.

A Generalisation of Diatonicism and the Discrete Fourier Transform as a Mean for Classifying and Characterising Musical Scales

Julien Junod, IRCAM Equipe des Représentations Musicales
Pierre Audétat, University of Applied Sciences Western Switzerland
Carlos Agon, IRCAM Equipe des Représentations Musicales
Moreno Andreatta, IRCAM Equipe des Représentations Musicales

Two approaches for characterising scales are presented and compared in this paper. The first one was proposed three years ago by the musician and composer Pierre Audétat, who developed a numerical and graphical representation of the 66 heptatonic scales and their 462 modes, a new cartography called the *Diatonic Bell*. It allows sorting and classifying the scales according to their similarity to the diatonic scale. The second approach uses the Discrete Fourier Transform (DFT) to investigate the geometry of scales in the chromatic circle. The study of its coefficients brings to light some scales, not necessarily the diatonic one, showing remarkable configurations. However, it does not lead to an evident classification, or linear ordering of scales.

Please join us in room 108 of the Whitney Humanities Center for coffee & snacks before the Poster Session.

Poster Session, 4:00 – 6:00
Whitney Humanities Center, 2d Floor

Quantitative Metric for Tonality Morphology in the Tonnetz Torus

Reinhold Behringer, Leeds Metropolitan University

Many approaches for investigating the morphology of Western tonality are of a qualitative nature, describing relations among pitches in a non-numerical way. In this poster, the approaches of Spiral Array and Tonnetz have been revisited to become numeric quantitative tools. This was possible through the assumption that the intervals Minor and Major Thirds are equivalent in their consonance and hereby can be represented by the same "distance" in the spatial array representation. This allows the determination of the ratio of height and radius in the Spiral Array, which leads to a concrete numerical result for Fifth and Third distance.

The Voice-Leading Automorphism on Neo-Riemannian Operators

Maxx Hyeok Cho, Swarthmore University

In the early formulations of Riemannian music theory, the Riemannian operators were defined at least in part by their voice-leading properties. However, some have suggested a root-intervallic approach to the operators. This has the advantage of crystallizing the operators' algebraic properties, but has the disadvantage of abandoning their voice-leading properties. In this paper, we show that there exist classes of set classes for which it is possible to define automorphisms on the Riemannian group that preserve their voice-leading properties.

Melodic Variation: Toward Cross-Cultural Transformation

Cheng-Zhi Anna Huang, Harvard University | MIT Media Lab

Culture nurtures unique musical styles, offering us rich palettes to augment our expressions for new experiences. Cross-cultural transformation is the process of recomposing music from one cultural musical style into another. Instead of attempting to find equivalences across cultures, I propose to approach cross-cultural transformation as a kind of theme and variation. This framework allows us to explicitly address the different levels of structure and consider which musical elements to stay fixed and which to vary in a cross-cultural context.

In this poster, I focus on melody and formalize the process of composing a cross-cultural theme and variation as a four-step process which includes first "melodic reduction" and "forward cross-cultural transformation" where the uncovered melodic progressions of the theme are mapped to those idiomatic in the cultural style that carries the variation, and then "melodic elaboration" and "backward cross-cultural transformation" where the elaborated melodic surface of the variation is adjusted to strengthen its resemblance to the theme.

I illustrate the above processes by a case study of the melodic variations on two historically related zithers, the Chinese gu-zheng and the Japanese koto, as they exhibit structural similarities underneath their distinct melodic surfaces. I give a preliminary short example of a koto melody transformed onto the gu-zheng style, and present an early prototype of a computer-assisted compositional tool to make composing across cultural boundaries more accessible.

Microtonal Serial Procedures in Ben Johnston's Second String Quartet, Mvt. I

Daniel Huey, University of Massachusetts, Amherst

Ben Johnston expanded the gamut of pitches in serial composition from twelve equal-tempered pitches to fifty-three, by exploring the microtonal possibilities of just intonation. The first movement of Johnston's Second String Quartet uses a 53-pitch scale. Each twelve-tone row begins on successively ascending pitches of this scale. I will explore these structures and explain the subset construction of the three different row forms used in this quartet.

Each row form may be mapped onto a tonnetz, which shows successively-tuned Pythagorean fifths in its columns and just-tuned major thirds in its rows. This tonnetz makes it possible to visualize the pitch material of microtonal rows. Corresponding lines of similar direction and distance on the tonnetz are equivalent intervals in just-tuned pitch space. Johnston composed the three rows in this quartet to accommodate the three different sizes of intervals in the ascending 53-tone scale. The scalar interval determines the row type used.

Johnston's approach added new sonic possibilities to serial compositional practice. His expansion of the pitch domain not only fit the spirit of exploration of serial procedures, but also established a creative pathway he would continue to follow throughout the 1960s.

Automated Layout of Schenker Graphs by Computer

Phillip Kirlin, University of Massachusetts, Amherst

Music analysts and music theory students often need to create Schenker graphs in their daily work when analyzing music. These graphs, which superficially resemble excerpts of common music notation, can be drawn by hand or created using a piece of computer software called a scorewriter. Scorewriters, like Finale and Sibelius, are notoriously difficult and frustrating to use to create and edit Schenker graphs. These programs, designed usually for common music notation, make numerous assumptions that are immensely helpful in typesetting most Western music, but often hinder the process of laying out a Schenker graph. We have constructed a tool, ss2ly, that reads an abstract representation of a Schenker graph from a text file (prepared by a human) and generates an output file that when processed by the music typesetter LilyPond, produces an accurate pictorial representation of the Schenker graph. The generated graphics are suitable for inclusion in any paper or publication that requires Schenker graphs. The input to ss2ly describes the notes present in the Schenker graph along with any slurs and beams connecting the notes, and any pieces of text that should appear close to specific notes.

The Editorial Board of the Journal of Mathematics and Music will meet from 7:30 to 9:00 in room 107 of Stoeckel Hall (corner of College and Wall streets)

Coffee & breakfast will be served at 8:00
in room 108 of the Whitney Humanities Center.

Tutorials, 9:00 – 12:00
(see individual tutorials for locations)

A Tutorial on Mathematical Models in Computer-Aided Music Theory, Analysis and Composition via OpenMusic
Carlos Agon and Moreno Andreatta, IRCAM

Whitney Humanities Center, Auditorium

In this tutorial we present some mathematical models in music theory, analysis and composition by using *OpenMusic* visual programming language. After briefly presenting some main *OpenMusic* functions that provide some musical examples of the use of symmetry in the tonal music tradition, we will discuss well-known music-theoretical and analytical paradigms, as Pitch Class Set Theory or Transformational Theory by using *OpenMusic* specialized package "MathsTools". The *OpenMusic* implementation of these concept leads to a paradigmatic architecture which gives the possibility to approach music analysis with a more firmly established theoretical background. By contrasting the paradigmatic approach, we will also present some new tools linked to discrete Fourier Transform and cyclotomic polynomials that have been recently integrated in *OpenMusic*. This includes a review of maximally even sets and related topics, which leads to new equivalence relations of musical structures without explicit reference to the theory of group action. The tutorial also includes the discussion of some computational models for computer aided musical analysis based on set-theoretical, transformational and Xenakis' sieve-oriented approaches. Pieces by Schoenberg (op. 19, No.4), Carter (*90+*) and Scriabin's *Piano Study* (Op. 65/3) will be presented by means of the *Maquette* tool and the still experimental *Sheet* environment. We conclude the tutorial by presenting a computer-aided analysis of several mathematically-based compositional processes used by composer's Iannis Xenakis in some of his pieces (from *Achorripsis*'s stochastic music to *Herma* and *Nomos Alpha* symbolic music).

Hands-on Workshop in Geometrical Music Theory

Rachel Hall, Saint Joseph's University

Stoeckel Hall, room 106

Although music theorists have used geometry to model musical objects such as chords, rhythms, and scales for centuries, so-called "geometrical music theory" is a relatively recent theory developed by Clifton Callender, Ian Quinn, and Dmitri Tymoczko (Callender 2004; Tymoczko 2006; Callender, Quinn, and Tymoczko 2008). Geometrical music theory recognizes that any musical object that can be represented by an n-tuple of pitches corresponds to a point in some n-dimensional Euclidean space. Common equivalence relations, such as octave and transpositional equivalence, define quotient maps on Euclidean space that produce a family of singular quotient spaces – orbifolds – that subsume many geometrical models previously proposed in the music theory literature. Points in these so-called *CQT spaces* correspond to familiar musical objects such as chords, scales, and chord types, while paths between points correspond to progressions from one object to another. The collection of CQT spaces includes tori, the Möbius strip, and other orbifolds whose complex geometrical properties have musical ramifications.

This workshop covers the basics of geometrical music theory in a series of exercises. Participants will investigate applications to scale theory, construction of voice leadings, and similarity measures for chord types and set classes. The workshop is intended for researchers and students in mathematics and music who wish to gain familiarity with geometrical techniques. I expect that participants will have, at a minimum, a basic mathematical background (including Euclidean geometry) and an understanding of musical set theory. Some of the problems discussed have implications in pure mathematics beyond music theory.

Measuring the Complexity of Musical Rhythm: Mathematical and Psychological Models

Godfried T. Toussaint, McGill University

Whitney Humanities Center, room 208

This tutorial is concerned with techniques for measuring the complexity of musical rhythm. Empirical measures obtained from a variety of experiments with humans, as well as mathematical measures motivated by diverse musical and mathematical concepts are reviewed. The definition of mathematical measures of rhythm complexity presupposes mathematical methods for

representing rhythms in the first place. This tutorial focuses attention on symbolic representations of rhythm. In particular, the pros and cons of several symbolic notation methods will be discussed, including box-notation, binary sequence notation, braid notation, chronotonic notation, convex polygon notation, and inter-onset histogram notation. One class of complexity measures is based on the dissimilarity between a given rhythm and perfectly regular rhythms. Therefore various mathematical measures of rhythm dissimilarity are reviewed including: the Hamming, fuzzy Hamming, swap, directed swap, edit, chronotonic, and linear assignment distances. The mathematical measures of rhythm complexity may be classified into three broad categories: *syncopation* measures, *irregularity* measures, and *entropy* measures. Several examples in each class will be illustrated. The psychological measures include: *perceptual*, *performance*, and *beat-tapping* complexities. Experiments with these measures will be described. Experimental methodologies for comparing complexity measures with each other will also be illustrated with examples, including: spearman-rank correlation and phylogenetic-tree analyses. This tutorial is directed at researchers involved in music theory, music information retrieval, and computational ethnomusicology, as well as mathematicians and computer scientists interested in music. The concepts will be illustrated with examples of families of rhythms taken from different parts of the world.

Lunch will be served at 12:00 in the 2d-floor rotunda of Whitney Humanities Center.

Please join us at 1:00 for a general meeting of SMCM in the Whitney Humanities Center Auditorium.

Paper Session 4, 2:00 – 3:30
Whitney Humanities Center, Auditorium

Perception

Estimating the Tonalness of Transpositional Type Pitch-Class Sets Using Learned Tonal Key Spaces

Özgür Izmirli, Connecticut College

This paper proposes a method to estimate the tonalness of a pitch-class set using transpositional types. For each set under consideration the method uses the corresponding transpositional type to generate note collections from acoustical instrument sounds and subsequently calculates a learned projection of that set into a low-dimensional space. The structure in this representation is then compared to the structure of a low-dimensional tonal key space learned from audio recordings of labeled tonal music. The term tonalness refers to how strongly the input suggests congruence to pitch use distributions in common-practice tonality. The method is tested on pitch-class sets of cardinality 3 and compared with measures from other work.

Evaluating Tonal Distances between Pitch-Class Sets and Predicting Their Tonal Centres by Computational Models

Atte Tenkanen

The pitch-class set belongs to the core concepts within musical set theory. The mathematical properties of pitch-class sets (in terms of interval-class content, evenness, etc.) as well as their mutual relations to other sets have been widely studied. In this paper, we concentrate on investigating them as carriers of tonal implications. Results provided by four algorithmic models, which propose hypothetical tonal centres for pitch-class sets, are compared. In addition to finding reference pitch class(es) for each set class of cardinality 3-9, the models are used for evaluating tonal distances between pitch-class sets. They are applied as 'similarity measures' in conjunction with an automated, computer-aided analysis method called comparison set analysis.

[map page 1]

[map page 2]

Determining Feature Relevance in Subject Responses to Musical Stimuli

Morwaread M. Farbood, New York University
Bernd Schoner, ThingMagic Inc.

This paper presents a method that determines the relevance of a set of signals (musical features) given listener judgments of music in an experimental setting. Rather than using linear correlation methods, we allow for nonlinear relationships and multi-dimensional feature vectors. We first provide a methodology based on polynomial functions and the least-mean-square error measure. We then extend the methodology to arbitrary nonlinear function approximation techniques and introduce the Kullback-Leibler Distance as an alternative relevance metric. The method is demonstrated first with simple artificial data and then applied to analyze complex experimental data collected to examine the perception of musical tension.

Coffee & snacks will be served between Paper Sessions 4 and 5 in room 108 of the Whitney Humanities Center.

Paper Session 5, 4:00 – 5:30
Whitney Humanities Center, Auditorium

Time

Speech Rhythms and Metric Frames

Fernando Benadon, American University

I present some conceptual and computational tactics related to the metric analysis of speech rhythms. An utterance can be considered metered when it approaches isochrony at the level of the syllable (note) and/or foot (beat). Since the timing patterns of spoken speech resemble those of music, we can apply knowledge of musical meter and expressive timing to the study of speech. However, speech rhythms tend to be more amorphous than musical rhythms, which makes the task of modeling meter in speech far from straightforward. The lack of a score or implicit rhythmic template leads to a meter-finding methodology that juggles the oftentimes incompatible outcomes of different metric frameworks: quantization as opposed to categorical perception, and subdivision isochrony as opposed to beat isochrony.

Temporal Patterns in Polyphony

Mathieu Bergeron and Darrell Conklin, City University London

This paper formally characterizes the expressiveness of three approaches for polyphonic pattern representation and matching: *R* (relational patterns); *H* (Humdrum); and *SPP* (Structured Polyphonic Patterns). Relational networks have the highest expressiveness but *H* and *SPP* admit faster matching algorithms. It is shown how *H* and *SPP* can be cast as different restrictions of *R*, both providing an expressive subset of full relational networks. In addition, the intersection of *H* and *SPP* yields yet another language: SPP_{seq}, a restriction of *SPP* based on sequences of layered components. This new language is expressive enough to capture basic polyphonic patterns such as suspensions and parallel fifths and may be a new, more efficient approach to pattern extraction. The formal arguments contained in this paper are illustrated with musical examples extracted from J.S. Bach chorale harmonizations.

A Multi-tiered Approach for Analyzing Expressive Timing in Music Performance

Panayotis Mavromatis, New York University

This paper presents a method for analyzing expressive timing data from music performances. The goal is to uncover rules which explain a performer's systematic timing manipulations in terms of structural features of the music such as form, harmonic progression, texture,and rhythm. A multi-tiered approach is adopted, in which one first identifies a continuous *tempo curve* by performing non-linear regression on the durations of performed time spans at all levels in the metric hierarchy. Once the effect of tempo has been factored out, subsequent tiers of analysis examine how the performed subdivision of each metric layer (e.g., quarter note) typically deviates from an even rendering of the next lowest layer (e.g., two equal eighth notes) as a function of time. Structural features in the music are identified that contribute to a performer's tempo fluctuations and metric deviations.

Evening Panel, 7:30 – 9:00
Whitney Humanities Center, Auditorium

Embodiment of Mathematical Formulas in Musical Gestures?

Organizer: Guerino Mazzola
Moderator: Emmanuel Amiot
Additional Panelists: Moreno Andreatta, Ian Quinn, Thomas Noll

(Due to Guerino Mazzola's absence, this panel is subject to change or cancellation.)

The panel focuses on the critical and provocative question: whether, and if so how far, mathematical formulas can be embodied in, and be made understandable through, musical gestures. Fourier's formula is omnipresent in the sciences. In acoustics, it describes how a complex sound wave is composed from a spectrum of sinusoidal overtones. However, the abstract formula can be difficult to understand. In our project, we unveil its mystery and communicate it to the public by means of a traditional Indonesian dance. The project not only provides a faithful "dancing of Fourier's formula", but also a reflection of the dance gestures within the spectral components of Tsuda's original composition. Rotating dancers, configured according to bodies in the solar system, represent overtones. Electronic position and movement trackers transmit dance movements to a computer system to generate complex sounds in real time. Three "police dancers" act violently on the "overtone dancers," distorting the corresponding musical sounds. The video of the premiere serves as rich material inviting scientific and artistic perspectives on mathematics and music by a panel of experts.

Coffee & breakfast will be served at 8:00
in room 108 of the Whitney Humanities Center.

Paper Session 6, 9:00 – 12:00
Whitney Humanities Center, Auditorium

New Interdisciplinary Approaches

Representing and Estimating Musical Expression in Melody

Christopher Raphael, Indiana University

A method for expressive melody synthesis is presented seeking to capture the prosodic (stress, direction, and grouping) element of musical interpretation. An expressive performance is represented as a note-level annotation, classifying each note according to a small alphabet of symbols describing the role of the note within a larger context. An audio performance of the melody is represented in terms of two functions describing the time-evolving frequency and intensity. A method is presented that transforms the expressive annotation into the frequency and intensity functions, thus giving the audio performance. The problem of expressive rendering is then cast as estimation of the most likely sequence of hidden variables corresponding to the prosodic annotation. Examples are presented on a dataset of around 50 folk-like melodies, realized both from hand-marked and estimated annotations.

HMM Analysis of Musical Structure: Identification of Latent Variables Through Topology-Sensitive Model Selection

Panayotis Mavromatis, New York University

Hidden Markov Models (HMMs) have been successfully employed in the exploration and modeling of musical structure, with applications in Music Information Retrieval. This paper focuses on an aspect of HMM training that remains relatively unexplored in musical applications, namely the determination of HMM topology. We demonstrate that this complex problem can be effectively addressed through search over model topology space, conducted by HMM state merging and/or splitting. Once successfully identified, the HMM topology that is optimal with respect to a given data set can help identify hidden

(latent) variables that are important in shaping the data set's visible structure. These variables are identified by suitable interpretation of the HMM states for the selected topology. As an illustration, we present two case studies that successfully tackle two classic problems in music computation, namely (i) algorithmic statistical segmentation and (ii) meter induction from a sequence of durational patterns.

Plain and Twisted Adjoints of Well-Formed Words

David Clampitt, Ohio State University
Manuel Domínguez
Thomas Noll, Escola Superior de Musica de Catalunya

This paper studies the mathematical basis for a new study of modes of well-formed (WF) scales, and presents a new characterization of special standard Sturmian morphisms. We introduce WF words, which coincide with the step-interval patterns of modes of well-formed scales. WF words can be represented as conjugates of some Christoffel word (generalized Lydian mode). To every WF word we may assign a pair of affine automorphisms f_w and g_w. These assignments induce a pair of involutions over the set of WF words: the *plain adjoint* and the *twisted adjoint*. We study the properties of these adjoints; in particular we show how the plain adjoint coincides with duality over the set of Christoffel words and also that the twisted adjoint extends Sturmian involution to the set of WF words. Thomas Noll's *divider incidence* result holds, *inter alia*, that w is special standard if and only if $f_w(1) = 1$.

A Declarative Language for Dynamic Multimedia Interaction Systems

Carlos Olarte, École Polytechnique, Pontificia Universidad Javeriana Cali
Camilo Rueda, Pontificia Universidad Javeriana Cali | Institut de Recherche et Coordination Acoustique/Musique

Universal Timed Concurrent Constraint Programming (UTCC) is a declarative model for concurrency tied to logic. It aims at specifying mobile reactive systems, i.e., systems that continuously interact with the environment and may change their communication structure. In this paper we argue for UTCC as a declarative model for dynamic multimedia interaction systems. Firstly, we show that the notion of constraints as partial information allows us to neatly define temporal relations between interactive agents or events. Secondly, we show that mobility in UTCC allows for the specification of more flexible and expressive systems. Thirdly, by relying on the underlying temporal logic in UTCC, we show how non-trivial temporal properties of the model can be verified. We give two

compelling applications of our approach. We propose a model for dynamic interactive scores where interactive points can be defined to adapt the hierarchical structure of the score depending on the information inferred from the environment. We then broaden the interaction mechanisms available for the composer in previous (more static) models. We also model a music improvisation system based on the factor oracle that scales up to situations involving several players, learners and improvisers.

Towards a Symbolic Approach to Sound Analysis

Carmine Emanuele Cella, Università degli studi di Bologna

In this article we will propose a new approach for music description, based on the connection between the symbolic (logic) level and the signal level. This approach relies on the possibility of representing sounds in terms of *types* inferred by some low-level descriptions of signals and subsequent learning stages. We will present *simple type theory* and we will introduce a twofold process to create *aggregate* representations with different degrees of abstraction thus making possible to describe and manipulate music at *variable* conceptual levels.

Compatibility of the Different Tuning Systems in an Orchestra

Alfonso del Corral, Taller de Música Jove
Teresa León, Universidad de Valencia
Vicente Liern, Universidad de Valencia

Focusing on the daily practice of musicians, we give flexibility to the mathematical treatment of musical notes, tuning systems and the relations between them. This allows us to connect the theory and the practice of music. Using the techniques of fuzzy logic, we describe the concepts with fuzzy sets and introduce the a-compatibility as a degree of interchangeability between tuning systems. To show how our proposal works, we use a fragment of Haydn and analyze the compatibility of the notes taken from 48 recordings for the tuning systems of Pythagoras, Zarlino and Equal Temperament of 12 notes.

Visitor Attractions

International Festival of Arts and Ideas

Every year in June, New Haven sparkles as the International Festival of Arts & Ideas displays a rare collection of gems: stunning music and dance, brilliant theater, bright and emergent thinkers gathered from around the world. From the New Haven Green to the courtyards of Yale University, New Haven becomes a Festival city with something for everyone, featuring world-class culture, award-winning dining and eclectic shopping, delighting guests from near and far. This year the festival will be held June 13–27. For up-to-date program listings, please go to the festival's website (www.artidea.org).

Yale Campus Tour

Yale Visitor Information Center, 149 Elm Street, 432-2300. Office is open 9-4:30 on weekdays, 11-4 on weekends. Free Campus tours offered Monday through Friday at 10:30 and 2:00; Saturday and Sunday at 1:30. For information and rates on special group tours, call 432-2300.

Yale University Art Gallery

1111 Chapel Street, 432-0600. Founded in 1832, the Gallery has a broad collection representing major movements and artists from ancient times to the present. YUAG sponsors programs that are free and open to the public, including special events, gallery talks and tours. The Gallery is open 10-5 Tuesday through Saturday, 1-6 on Sunday, and closed Monday and major holidays.

Yale Center for British Art

1080 Chapel Street, 432-2800. Housed in the last building designed by American architect Louis Kahn, the Center offers the largest collection of British art outside the United Kingdom, available for public viewing at no charge. The BAC is open Tuesday through Saturday from 10-5, Sunday 12-5 and closed Monday and major holidays.

Yale Peabody Museum of Natural History

170 Whitney Avenue, 432-5050. Group tour information 432- 3775. Amazing exhibits of dinosaur fossils, wildlife dioramas and Connecticut birds, plus Egyptian and other ancient cultures. Open Monday through Saturday, from 10-5, Sunday 12-5, and closed holidays. Admission: adult $7, senior citizens $6, and children ages 3-18 $5, free for children under three and members of the Yale community with ID.

Beinecke Rare Book and Manuscript Library

121 Wall Street, 432-2972. Contains four major collections: the General Collection of Rare Books and Manuscripts, the Yale Collection of American Literature, the German Literature Collection, and the Osborn Collection of English Literary and Historical Manuscripts. The exhibition area is open Monday through Thursday 8:30-8, Friday 8:30-5 and Saturday 10-5 (except during recesses), and closed Sunday. Admission is free.

Yale Collection of Musical Instruments

15 Hillhouse Avenue, 432-0822. Collection of 800 antique and historical musical instruments from the 16th-19th centuries. Open Tuesday through Thursday, 1-4. Closed during July, August, and recesses.

The New Haven Green and its Churches

Located in downtown New Haven, the Green is the central of the nine "squares" in the city's 1638 village plan. Its three churches are outstanding examples of Gothic, Federalist and Georgian design. The Green is a National Historic Landmark. Center Church is located in the center of the New Haven Green at 250 Temple Street. This landmark was built over New Haven's Old Colonial Burying Ground. Located in its crypt are the resting places of New Haven's founders, including Benedict Arnold's first wife! Open hours are Thursday 11-1. Tours of the crypt are held every Sunday following 10 services. Trinity Church is located at the corner of Temple and Chapel Streets on the New Haven Green and was one of the first Gothic Revival churches in America. Trinity Church is available for viewing by appointment only. Call the Sexton at 624-3101 United Church is located at Temple and Elm Streets and offers tours of this historic meetinghouse by reservation only. Its shallow domes, beautiful ceiling ornaments, and glorious chandelier are part of the original décor. For appointments, call 787-4195.

New-Haven Historical Society

114 Whitney Avenue, 562-4183. Historical exhibits, research library, re-created colonial rooms, permanent decorative art gallery with tableware of New Haven 1640-1840, antique dolls and toys. Open Tuesday through Friday 10-5 and weekends 2-5. Admission: adults $2, senior citizens $1.50.

Grove Street Cemetery

227 Grove Street, 787-1443. Open year round, 8-3:30. Admission is free. The cemetery gate, built by Henry Austin in 1845, is the finest of several Egyptian Revival gates built in New England in the mid-19th century. Buried in the cemetery are Eli Whitney, inventor of the cotton gin, Noah Webster, of dictionary fame, and many famous Yale graduates and New Haven residents.

Restaurants

The following listings are only a sample of New Haven cuisine. If you find another restaurant that we should include, just let us know and we will add it to the next guide.

American

Bespoke: Modern American food with global influences. Open for dinner Tuesday-Sunday. 266 College St., 562-4644 ($$$)

The Blue Pearl: Creative American dishes at affordable prices. 130 Court St., 789-6370 ($$)

Carmen Anthony Steakhouse: A myriad of steaks and other American classics, including clam chowder, which was voted Connecticut's best. 660 State St., 773-1444 ($$$)

Central Steakhouse: Elegant dining area, world-class aged beef, with a supporting cast of grilled sides, vegetarian cuisine, and fresh seafood. 99 Orange St., 787-7885 ($$$)

Claire's Corner Copia: Vegetarian menu. Breakfast, lunch, dinner, and desserts. 1000 Chapel St., 562-3888 ($$)

Copper Kitchen: Breakfast daily from 6am. Goulash, beef stew, gyros. 1008 Chapel St., 777-8010 ($)

Diner 21: Classic american eatery. Open late. 21 Temple St., 787-2121 ($)

The Educated Burgher: Omelets, burgers, fries, sandwiches, etc. 53 Broadway, 777-9198 ($)

Joe's Hubba Hubba: Open for breakfast, lunch or dinner. Serves sandwiches, wraps, and its famous chili. 135 Orange St., 773-1000 ($)

John Davenport's at the top of the Park: Rooftop restaurant and bar that boasts contemporary American cuisine and an amazing panoramic view of the city. Located in the Omni Hotel, 155 Temple St., 772-6664 ($$-$$$)
Judies European Bakery: Award-winning coffee shop and café offering breakfast and lunch, fresh baked breads and modern cakes and confections. 63 Grove St., 777-6300 ($$)
Katz's 2 Go Deli: Jewish style deli open for lunch in the heart of New Haven., 167 Orange St. 787-5289
Katz's II on Temple. Classic full-service New York style deli serving breakfast, lunch, and dinner, including sandwiches, salads, and soup. 21 Temple St., 787-5289
Louis' Lunch: Most famous little grill in town. Claims to have invented the American hamburger. 263 Crown St., 562-5507 ($)
Nikkita: An eclectic mix of American, Italian, Thai, and Asian cuisine with a modern, multicultural flare. 200 Crown St., 787-0227 ($$-$$$)
Richter's Café: Turn of the century pub serving beers, soups, and sandwiches. 990 Chapel St., 777-0400 ($$)
Sandra's Place: Generous portions of American Soul food. BBQ, fried chicken, pork chops, greens, fried okra, cornbread, and more. 46 Whitney Ave., 787-4123 ($$)
Sullivan's: American fare in an Irish pub atmosphere. 1166 Chapel St., 777-4367 ($$)
Sweet Relief: Healthy soups, wrap sandwiches and smoothies. 99 Audubon St., 789-9800 ($$)
Swings: Features a wide selection of all types of wings. 280 Crown St., 562-9464 ($$)
Temple Grill: Comfort foods with an edge- salads, burgers, sandwiches, and pastas. Lunch and dinner 7 days a week. 152 Temple St., 773-1111 ($$)
Yankee Doodle: Popular diner with great burgers. 258 Elm St., 865-1074 ($)
Zinc: Creative American and ethnic dishes in a formal atmosphere. 964 Chapel St., 624-0507 ($$$)

Asian

Bangkok Gardens: Excellent Thai food, in a comfortable atmosphere. 172 York St., 789-8684 ($$)
Bentara Restaurant: Authentic Malaysian cuisine with award-winning wine list. 76 Orange St., 562-2511 ($$)
China King: Take-out style menu with large portions. 942 Chapel St., 776-8807. ($)
Haya's: Intimate atmosphere specializing in sushi and other authentic Japanese cuisine. 93 Whitney Ave., 562-3022 ($$)

Indochine Pavilion: Traditional Vietnamese cuisine with nightly dinner specials. 1180 Chapel St., 865-5033 ($$)
Ivy Noodle: Chinese cuisine specializing in noodles and soup. Take out available. 316 Elm St., 562-8800 ($)
Kudeta: Asian Fusion in a modern captivating atmosphere. 27 Temple St. , 562-8844..($$)
Main Garden: Large menu and sizeable portions for a great price. Delivery and take-out. 376 Elm St., 777-3747 ($)
Miso Restaurant: Fresh, creative sushi dishes, tasty choices off the grill and a taste of Japanese elegance. 15 Orange St., 848-6473 ($$-$$$)
Miya's Sushi: Impressive Japanese cuisine and sushi bar. 68 Howe St., 777-9760 ($$)
Pad Thai: Thai cuisine at great prices. 1170 Chapel St., 562-0322 ($)
Royal Palace: .Delicious Cantonese and Schezuan dishes; take-out available. 32 Orange St., 776-6663 ($$-$$$)
Samurai: Full Japanese menu specializing in sushi. 230 College St., 562-6766 ($)
Seoul Restaurant: A popular Korean restaurant. Lunch, dinner. 343 Crown St., 497-9634 ($$)
Thai Pan Asian Restaurant: Japanese, Chinese, and Thai cuisines. 1150 Chapel St., 752-9898 ($$)
Thai Taste: Superb Thai cuisine with great service. 1151 Chapel St., 776-9802 ($$)
York St. Noodle House: Budget Chinese cuisine. Take out available. 166 York St., 776-9675 ($)

Ethiopian

Caffé Adulis: Traditional Eritrean and continental cuisine in a comfortable setting. 228 College St., 777-5081 ($$-$$$)
Lalibela: Traditional Ethiopian cuisine, specializing in vegetarian dishes. 176 Temple St., 789-1232 ($$)

French

Gastronomique: Gourmet take-out and fresh juice bar. 25 High St., 776-7007 ($)
Union League Café: Gourmet French fare including bistro meals and impressive desserts. Open for dinner daily and lunch Mon-Fri. Closed on Sundays. Call for reservations. 1032 Chapel St., 562-4299 ($$$)

Indian

Royal India: Indian food that tastes too authentic to be true. 140 Howe St., 787-9493 ($$)
Tandoor: A 50's diner gone Indian! A favorite among students. 1226 Chapel St., 776-6620 ($$)
Sitar: Fine Indian Cuisine. 45 Grove St. 777-3234 ($$$)
Zaroka: Standard Indian fare, including south Indian items on occasion. Buffet at lunchtime seven days a week. 148 York St., 776-8644 ($$)

Irish

Anna Liffey's: Irish pub and restaurant. Meals, music, and beer. 17 Whitney Ave., 773-1776 ($$)
Celtica: Charming Irish tea room. Lunch menu also available. 260 College St., 785-8034 ($$)
The Playwright: Irish standards plus some wonderful new tastes, including seafood, pasta, and other specials. Popular night spot. 144 Temple St., 752-0450 ($$)

Italian

The Backroom @ Bottega: Full bar, extensive wine list. Appetizers and desserts available. Indoor and outdoor seating; nightclub atmosphere. 954 Chapel St., 562-5566 ($$-$$$)
Basta Trattoria: Fine Southern Italian cuisine in a casual atmosphere. 1006 Chapel St., 772-1715 ($$)
Caffé Bottega: European style breakfast, lunch, dinner & freshly-made gelato. 910 Chapel St., 624-6200 ($$)
Hot Tomato's: Eclectic Italian cuisine. 261 College St., 624-6331 ($$$)
L'Oricio: Fine Italian cuisine in an upscale atmosphere. Reservations recommended, Closed Mondays. 806 State St., 777-6670 ($$$)
Nini's Bistro: Prix-fixe B.Y.O.B. Intimate spot, Italian and French dishes. 40 Orange St., 562-6464 ($$-$$$)
Quattro's Italian Cuisine:Exquisite Italian menu with attentive service. 172 Temple St., 787-6702 ($$)
Scoozzi Trattoria and Wine Bar: Large selection of wines, pastas, breads, thin crust pizzas with toppings such as Cajun sausage, brie and duck. Summer patio offers the best al fresco dining in town. 1104 Chapel St., 776-8268 ($$ $)

Latinerican/Carribean

Pacifico: Nuevo Latino cuisine specializing in seafood. 220 College St., 772-4002 ($$$)
Soul de Cuba: Traditional home-style Cuban food in a cozy and festive atmosphere. 283 Crown St., 498-2822 ($$)

Mexican

Bulldog Burrito: Offers both take-out and on-site dining in an informal setting. 320 Elm St., 562-6394 ($)
Fresh Taco: Inexpensive Mexican fare, served quickly. Self-service. Take out available. 39 Elm St., 777-3068 ($)
La Casita: Newly opened, serving a variety of Mexican dishes. 182 Temple St . ($)
The Whole Enchilada: Mexican food and fat-free soups. 21 Whitney Ave., 772-4454 ($)

Middle Eastern

Mamoun's Falafel Restaurant: Sandwiches and vegetarian specialties, including hummus, makdoos & falafel. Open until 3am. B.Y.O.B. 85 Howe St., 562-8444 ($)
King Falafel: Hearty Middle Eastern favorites, featuring falafel dishes. 240 College St., 848-3076 ($-$$)
Sahara: Falafel, hummus, makdoos, shoarma, pizza and more. 170 Temple St., 773-3306 ($)

Pizza

Aladdin and Crown Pizza: Middle Eastern food plus Greek pizza equals delicious! Try the gyros or falafel. 260 Crown St., 773-3772 ($)
Alpha Delta Pizza: Pizza, kebabs, and subs. Open late. Delivery and take out available. 371 Elm St., 787-3333 ($)
A One Pizza: 24-hour pizza and breakfast featuring 21 burgers and vegetarian options. 21 Broadway, 865-8888 ($)
Avanti Ristorante and Pizzeria: Only the service is cafeteria style. Offers seafood, pizza, spaghetti, and ravioli. Hours: 11:30-5:00. 45 Grove St., 777-3234 ($$)
Clark's Pizza and Restaurant: Features large Greek salads, pizza, daily lunch and dinner specials and great ice cream next door. 68 Whitney Ave., 776-8465 ($-$$)

Est Est Est: Specializes in Italian favorites and pizza in a relaxed atmosphere. 1176 Chapel St., 777-2059 ($$)
Frank Pepe's Pizza: Arguably New Haven's best pizza. 157 Wooster St., 865-5762 ($-$$)
Modern Apizza: The Advocate's pick for New Haven's best pizza. 874 State St., 776-5306 ($$)
Naples: Features pizza, sandwiches and more. 90 Wall St., 776-9021 ($)
Pizza at the Brick Oven: Thin crusted brick oven baked pizza. 122 Howe St., 777-4444 ($)
Sally's Apizza: Another contender for New Haven's best pizza. 237 Wooster St., 624-5271 ($-$$)
Town Restaurant: Pizza, subs, gyros, Greek salads. 25 Whitney Ave., 865-6065 ($)
Yorkside Pizza: Pizza, subs, hamburgers, salads and Greek food. 288 York St., 787-7471 ($-$$)

Spanish

Ibiza: Spanish cuisine featuring authentic tapas, both meat and vegetarian. 39 High St., 865-1933 ($$$)
Barcelona: Exciting Spanish cuisine, including tapas, in a modern space. 155 Temple St., 848-3000 ($$-$$$)

Sweet Tooth

Ashley's Ice Cream: Voted the best ice cream in Connecticut, features homemade ice cream, frozen yogurt and sorbet. 280 York St., 776-7744 ($)
Chapel Sweet Shoppe: Ice cream, Belgian chocolates and other candies. 1042 Chapel St., 624-2411 ($)

Turkish

Istanbul Cafe: Authentic Turkish cuisine. 245 Crown St., 787-3881 ($$)

Coffee Houses

Au Bon Pain: Gourmet café serving pastry and sandwiches. 1 Broadway, 865-5554 ($$)
Atticus Bookstore Café: Sandwiches, soups, salads, baked goods and coffee. 1082 Chapel St., 776-4040 ($$)

Blue State Coffee: Locally roasted coffee. The owners contribute 5% of their revenues to progressive political causes selected by customers. 84 Wall St., 764-2632 ($)

Book Trader Café: Light menu, great coffee. 1140 Chapel St., 787-6147 ($$)

Bruegger 's Bagels: Fresh-baked bagels, soups, sandwiches and salads 1 Whitney Ave.,773-3199 Dunkin' Donuts: Donuts, bagels and coffee. 1179 Chapel St., 624-1107; 54 Whitney Ave., 562-6933 ($)

Koffee?: Coffee and tea beverages, sandwiches, and baked goods. 104 Audubon St., 562-5454 ($)

Koffee Too?: A branch of the Audubon St. original. 276 York St., 787-9929 ($)

Moka: A chocolate cafe featuring beverages and sweets. 141 Orange St., 752-0052 ($)

Oolong's Tea Bar: A cozy tea shop serving looseleaf tea, pastries, and bubble tea. 1044 Chapel St. (in Sherman's Alley), 752-0178 ($-$$)

Starbucks: Coffee, tea, and pastries. 1070 Chapel Street, 624-3361 ($)

Willoughby's: An array of coffee and tea beverages. 1006 Chapel St., 789-8400, 258 Church St., 777-7400 ($)