Music Perception & Cognition
HST 725

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Outline
• Course mechanics
• Class survey
• Music, mind, and brain
  – FORM & QUALITY
  – PATTERNS OF EVENTS IN TIME
  – NEURAL MECHANISMS
  – MEMORY/GROUPING
  – EMOTION/MEANING
  – ORIGINS
• Overview of topics
• Music introduction

Wednesday, February 4, 2009
Johann Sebastian Bach
Organ Triosonata in e minor
Third movement
Un poco Allegro
Texts

Texts: (Available at the MIT Coop and/or MIT Press Bookstore)


• Snyder, Bob. 2000. Music and Memory. MIT Press. (Currently required, may be optional, MIT Coop & MIT Press Bookstore)


• Levitin, D. 2006. This is Your Brain on Music. Required. (MIT Coop, optional)


Format

Format:
Lecture format + demonstrations, discussions & presentations.
Begin promptly at 7 PM.

We will always have a 5-10' break at 8 PM.

Lecture
Music presentations, of one sort or another
Student presentation followed by discussion (when we do this)

For each aspect of music, we’ll try to cover topics in this order:
Music & sound (stimuli)
Psychoacoustics, psychology (listener’s response, incl. our own)
Neurocomputational models (information processing theories)
Possible neurobiological substrates (neurophysiology)

We will also go back and forth between bottom-up approaches to particular aspects and their relevance to music as a whole.
Class meeting timeline

50' Stretch

5-10' Break

50' Music
My trajectory

Organismic biology (undergrad @ MIT mid 1970s)

Biological cybernetics & epistemology (1980s)
  Biological alternatives to symbolic AI
  Howard Pattee, Systems Science, SUNY-Binghamton

Temporal coding of pitch & timbre (1990s-present)
  Auditory neurophysiology, neurocomputation

How is information represented in brains?
  Commonalities of coding across modality & phyla

Neural timing nets for temporal processing
  Auditory scene analysis
  Possibilities inherent in time codes
  Temporal alternatives to connectionism
    signal multiplexing; adaptive signal creation broadcast
My trajectory vis-a-vis music

Avid listener, but a mediocre musician

Very interested in music growing up, played violin (badly)

Attempted to teach myself music theory in HS

Heavily into baroque music & progressive rock

Electronic & dissonant "experimental" music

Took "sound sculpting" as an MIT undergrad

Worked with Bertrand Delgutte on neural coding of pitch

& Mark Tramo on consonance (1990's)

Developed timing nets for music (2000's)

Proposed course in music perception for Harvard-MIT

HST graduate speech & hearing program (2003)

Taught this course at Tufts in fall 2003

Taught graduate course @ MIT in 2004 & 2007

Teaching @ Tufts & MIT this term
Big questions (Whys and Hows)

• To be explained: the "unreasonable effectiveness" of music"
  (to paraphrase Wigner on the unreasonable effectiveness of mathematics in explaining the physical world)

• Why does music have its profound effects on us?

• How does the auditory system and the brain work such that music can have the effects that it does?
  – (to paraphrase Warren McCulloch, "What is a number that a man may know it, and a man that he may know a number?")
Organizing themes: Music, mind, and brain

- FORM & QUALITY OF SOUNDS (tones)
- PATTERNS OF EVENTS IN TIME (events)
- NEURAL MECHANISMS
- MEMORY & ORGANIZATION (grouping)
- EMOTION & MEANING, tension & relaxation
- ORIGINS: Why music?
Course rationale(s)

• Music is an important aspect of the auditory sense that rivals speech and language in complexity
• Many of us come to auditory research through a native interest in music
• Music affords an alternative perspective on hearing and neuroscience, spanning acoustics, sensory physiology, auditory perception & auditory cognition
• We strive to be systematic and integrative in our treatment (lecture format, common grounding)
• A primary goal is to facilitate intellectual synthesis; to organize disparate facts into coherent wholes
• We want students to choose & formulate their own problems, articulate their own perspectives, and delve deeply into an area of personal interest (fundamental problems, term projects)
General Plan

• Initial overview
  – Music, What we hear, How we hear

• Elements of music
  – Pitch, timbre, consonance, chords; neural representations

• Organizations of tone and event patterns
  – Melodies, Rhythmic patterns, expectancies; neuro-computations

• Effects --
  – anticipations and emotional-cognitive effects;
  – towards a functional neurology of music

• Origins & special topics (why music)
Tuesday Feb. 3
Course mechanics, introductions, and course design
Survey of topics to be covered

**Overview of the structure of music**
Horizontal and vertical dimensions. Pitch, tone quality/color, consonance, melody, harmony, tonality, organization of voices, rhythm, dynamics, expressive timing, tonal and rhythmic hierarchies

**Overview of music’s psychological and social functions**
Emotion & meaning, psychological and social functions of music.

Thursday, Feb. 5

**Overview of auditory perception and the time sense**
Pitch, timbre, consonance/roughness, loudness, rhythm, auditory grouping, event structure
Thursday, Feb 12  Pitch
Musical acoustics I - periodic sounds
Sound & vibration, production of sounds, representations of sound, waveforms & power spectra,
Psychophysics of pitch
Neurocomputational models for pitch – spectral pattern and temporal models
Licklider, Terhardt, Grossberg & Cohen, Bharucha
Representation of pitch in the auditory system, time & place
Neural evidence pros & cons
Pitch in object formation and separation

Tuesday, Feb. 17 NO CLASS -- PRESIDENTS' DAY (Monday class schedule)

Thursday, Feb. 19 Timbre
Musical acoustics II - complex tones and time-varying sounds
Sound & vibration, production of sounds, representations of sound, waveforms & power spectra, characteristics of musical instruments and human voices, similarities and differences between speech and musical sounds (“lexical music”)
Timbre - Acoustic correlates - spectrum, time-frequency trajectory, amplitude dynamics
Dimensional analysis of timbre perceptual spaces (multidimensional scaling)
Role of timbre in defining & distinguishing separate voices, musical coloration
   Neural correlates, coding of spectrum, attack, decay, modulation
Timbral space and phonetic contrasts; Tonal languages and music
Tuesday, Feb. 24  Consonance
Harmony I: Consonance, dissonance, and roughness
   Theories: Helmholtz, Stumpf, Plomp, Terhardt
Sensory and hedonic aspects
Neural correlates (auditory nerve, midbrain, cortex)
Scales and tuning systems
   History, basic psychophysics, scales and tuning systems, role in music theory
Relations between auditory and cultural factors

Thursday, Feb. 26
Harmony II: chords and keys
   Perception of chords, pitch multiplicity (Parncutt, Terhardt), higher order structure of pitch space (Shepard, Krumhansl), fundamental bass, keys, major-minor and resolved/unresolved chords, tonality induction, tonal schemas/key relations, computational models (Leman), neural correlates of tonal relations and expectations (fMRI, ERP)

Tuesday, March 3
Melody
   Perception of note sequences, existence region, melodic expectation, melodic recognition, melodic memory, melodic grouping processes (phrases), neural representation of melody, problem of melodic invariance under transposition
Thursday, March 5
Rhythm I: Rhythm perception and production
Basic psychophysics of rhythm perception and production
Role of rhythm in melodic recognition & recall
Rhythm II: Computational models
   Oscillator models, clock models, rhythmic hierarchies, timing nets
Time perception, event structure, and temporal expectations
Auditory spectral and temporal integration; chunking of segments
   Time perception (Fraisse, Jones)

Tuesday, March 10
Gestalts: Auditory scene analysis: grouping/chunking/
   Grouping of sounds – onset, harmonicity, rhythm
   Sound streams (Bregman, Deutsch), polyphony, polyrhythms
Grouping of tones and events
Grouping processes and musical structure
Common mechanisms; analogies in vision
State of automatic music recognition systems
Thursday, March 12 Music of the Hemispheres

Tuesday, March 17
Anticipation and expectancy

Thursday, March 19
Emotion and meaning in music: what it means to us (internal semantics, memory, fashion/identity, pleasure)
Music and psychological functions – activation of different circuits related to different uses/effects of music
Music and long-term memory: how can we remember melodies years later?
Innate vs. cultural determinants of musical expectation and preference

Week of March 23 No class – MIT Spring Break
Thursday, April 2  Music therapy  (K. Howland, music therapist)
• "Clinical applications of the neuropsychology of music." Guest speaker Kathleen M. Howland Ph.D., MT-BC, CCC-SLP. Clinical problems, current therapies, and prospects for new therapies.

Tuesday, April 7  Music and Cortical Function
Neurology of music, Effects of cortical lesions on music perception and cognition
Activation of circuits responsible for different musical functionalities

Thursday, April 9  Music, Speech & Language
• Music cognition and psycholinguistics, speech and language:
Parallels and contrasts between music, speech, and language (Bernstein, Jackendoff, Lerdahl)
Is there a grammar of music? Rule-following vs. rule-obeying systems. Symbols and categorical perception. What are the neurocomputational substrates for recognition of musical structure?

Tuesday, April 14  Developmental psychology of music
Developmental psychology of music – perception & cognition
Rhythmic expectation, melody perception, early preferences
Innate faculties vs. associative learning

Thursday, April 16  Evolutionary origins
The debate about the evolutionary psychology of music.
Tuesday, April 21   NO CLASS   Patriot’s Day Holiday

Thursday, April 23 Clinical issues

Tuesday, April 28  Creativity & performance
• Music performance & creativity. fMRI studies. Organization and timing of movement.

Thursday, April 30 Student Final Project Presentations

Tuesday, May 5     Student Final Project Presentations

Thursday, May 7 Special topics
• Special topics: absolute pitch & pitch memory, synesthesia, audio-visual parallels, etc.

Tuesday, May 12 Special topics
• Some possible topics: music performance (motor timing & sequencing), music & dance, spatial hearing, architectural acoustics

Thursday, May 14 Wrap-up and Recapitulation
• Overview and recap of major themes; other special topics
Coursework

Coursework:
• Problem sets (20%)
  One problem set will be on harmonic structure and tuning systems. The other will cover topics in music
  perception and cognition.

• Musical examples (10%)
  Find 5 musical examples from any genre that illustrate or illuminate different aspects of music perception &
  cognition related to melody, harmony, rhythm, your own musical preference, and some aspect of your
  choosing. We will listen to them as a class and discuss them.

• Reading assignment & presentation (10%)
  A relevant paper will be chosen, presented (10-15’), and discussed by the class. This can be one of the papers
  on the reading list or any paper that you feel is important or insightful.

• Fundamental unsolved questions in music psychology – 3-4 page outline/discussion (20%)
  I have compiled a list of unsolved questions in music psychology. Please choose from the list or suggest your
  own problem. Write up an account of the nature of the problem (1-2 paragraphs), its theoretical
  significance (1 paragraph), current theories (if any, 1-3 paragraphs), two plausible hypothetical
  explanations (2-4 paragraphs), ideas concerning how the question might be solved or hypotheses tested
  (1 paragraph), and some assessment of how soon the problem will likely be solved (1 paragraph). Each
  student will present a problem and outline their thinking about it, which will form the basis for a class
discussion.

• Term project (50% of final grade)
  A research paper, review paper, or research project (e.g. psychological or physiological experiment,
  computer model/simulation) related to the psychology of music. Topics will be presented orally and
  discussed in class in mid-March. Project results will be presented and discussed in class in the last two
weeks of class. Target length of paper will depend on nature of project. Final papers will be due on the
last day of class. I will be happy to read and give comment on outlines and drafts at any stage of
preparation.

Wednesday, February 4, 2009
An Introduction to Music:
Sound unfolding in time

Source: IMSLP.org
Sound unfolding in time: an introduction to music

- **Music**: a bird's eye view; provisional definition
- **Ubiquity of music**: Nature and nurture
- **Sound unfolding in time**
  - **Horizontal dimension** (time, sequential sounds)
    - Melody (Temporal patterns/sequences of pitches)
    - Chord progressions, key modulations (Temporal patterns/sequences of pitch relations)
    - Rhythm (Temporal patterns/sequences of events)
  - **Vertical dimension** (sound quality, concurrent sounds)
    - Pitch (Dominant periodicities) & Timbre (spectrum, frequency microdynamics)
    - Harmony (Constellations of concurrent pitches)
  - Number of independent trajectories: voices, streams
- **Relations to perceptual dimensions**
- **Psychological questions**
Music as stimulus, idea, action, and private experience

Psychology of music examines relations between music and mind.

Music is half of this relation.

Mind has different facets:
1st person experience
3rd person overt behavior
Underlying neural activity
Functional organization of informational processes
Music: a provisional definition

Deliberate organization of patterns of sound for interest or pleasure. Deliberate organization of auditory experience for interest or pleasure.

"Organization" can involve composition or performance or selection of sounds or even selective attention to sounds (Cage)
"Interest" and "pleasure" are similarly very broadly construed.
Ubiquity of music: Nature and nurture

• Music has been part of human culture for > 40,000 years
• Every known extant culture has some form of music
• Many cultures equate musical with social harmony (Greeks)
• Relative contributions of nature (biology) & nurture (culture) to the experience of music.
• A great deal of diversity exists across cultures in the forms music takes (ethnomusicology)
• There are universals related to how we hear that are given by biology (auditory science).
• But there are also the effects of culture-based training of how we hear (what aspects we attend to).
• There are also culturally-specific interpretations and meanings associated with what is heard.
• In these lectures we will focus mainly on the universals -- basic aspects of music that are shared across cultures.
• We want a general framework for talking about music that can encompass both the Western tonal music (classical, jazz, popular) as well
Horizontal and vertical dimensions

Tonal quality
(pitch, spectrum)

Time (beats, seconds)

successions of events, changes
Horizontal and vertical dimensions

Tonal quality
(pitch, spectrum)

Time (beats, seconds)

successions of events, changes
Horizontal and vertical dimensions

Tonal quality
(pitch, spectrum)

Time (beats, seconds)

successions of events, changes

http://www.well.com/user/smalin/compare.htm

Courtesy of Stephen Malinowski. Used with permission.
Horizontal and vertical dimensions

Tonal quality
(pitch, spectrum)

Density
Complexity
# independent trajectories

http://www.well.com/user/smalin/compare.htm

Courtesy of Stephen Malinowski. Used with permission.

Time (beats, seconds)
Horizontal dimension (time)

Temporal patterns and sequences of sound-changes

Melody: temporal patterns of pitches

Cadences, key modulations:
  temporal patterns of pitch constellations

Rhythm: temporal patterns of events

Bernstein on musical intervals and dimensions
Horizontal dimension (time)
Different musical cultures utilize different aspects of musical possibility. Ethnomusicologists, anthropologists, and historians have theories as to why cultures adopt particular musical styles.

Examples of music that are focused on melody.
(Traditional fiddle-playing in France -- video)
(Gasparyan, Armenian flute music)

Indian ragas

Examples of musics focused on chord progressions
Western symphonic "classical" music, Rock

Examples of music focused on rhythm
African drumming (many examples)
Mbira music, Senegal -- video
Vertical dimension (Harmony)

Patterns of concurrent sounds
Constellations of pitches (intervals, chords)
Sound texture (timbre)

Number of independent voices

Example of horizontal and vertical organization:
Satie Music Animation Machine

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Horizontal dimension involves temporal context & memory
Build-up of representations and expectancies
Vertical dimension involves tonal interactions
Masking, fusions of sounds
Rethinking the role of time

- Time as coding auditory quality (pitch, timbre, rhythm)

- Time as metrical structure of events
  Repetition and change in music
  Buildup of temporal pattern expectations

- Time as ordinal sequence of events

Perception, cognition, & motor domains
Auditory qualities in music perception & cognition

- **Pitch** Melody, harmony, consonance
- **Timbre** Instrument voices
- **Loudness** Dynamics
- **Organization** Fusions, objects. How many voices?
- **Rhythm** Temporal organization of events
- **Longer pattern** Repetition, sequence
- **Mnemonics** Familiarity
- **Hedonics** Pleasant/unpleasant
- **Semantics** Cognitive & emotional associations
Frequency ranges of (tonal) musical instruments

- > 6 kHz
- 2.5-4 kHz

27 Hz
110 Hz
262 Hz
440 Hz
880 Hz
4 kHz
Dimensions of auditory objects

Auditory qualities and their organization

Objects: Quasi-stationary assemblages of qualities

Pitch

Timbre

Loudness

Location

Spatial Dimensions

Dimensions of event perception

Unitary events & their organization

Events: abrupt perceptual discontinuities

TEMPORAL EVENT STRUCTURE

Timing & order (metric, sequence)

FUSION/SEPARATION

Common onset & harmonic structure => fusion
Different F0s, locations, onset => separation

POLYPHONY

FUSION/SEPARATION

Common onset, offset => fusion
Diff. meters, pitch, timbre => separation

STREAMS, POLYRHYTHMS
Music: patterns of events in time
organized relations between events
Music: patterns of events in time organized relations between events

Johannes Brahms
Capriccio
Opus 76 no. 2
From cochlea to cortex

10,000k
Primary auditory cortex
(Auditory forebrain)

500k
Inferior colliculus
(Auditory midbrain)

30k
Auditory brainstem

3k
Auditory nerve (VIII)

2k
Cochlea

Figure by MIT OpenCourseWare.
MECHANISM

Neurophysiology  Music cognition
Neurocomputation  Music theory

Wednesday, February 4, 2009
Neurophysiology
Neurocomputation

Neural responses
Neural codes
Neuroanatomy
Psychoacoustics
Reverse-engineering
Explaining pitch

Music cognition
Music theory

Schemas, grammars
Event structures
Tonal hierarchies
Memory
Aesthetics, hedonics
Pitch as a primitive
Visual grouping

Dember & Bagwell, 1985, A history of perception, Topics in the History of Psychology, Kimble & Schlesinger, eds.

Figure by MIT OpenCourseWare.
Acoustical grouping

(Snyder, Music & Memory)

SIMILARITY

Sequential Grouping
(Arrows indicate point of realization of change.)

Grouping  Grouping

Change in loudness

Grouping

Change in timbre

Grouping

Change in pitch interval

Simultaneous Grouping

Grouping

Grouping

Grouping

Melodic grouping & rhythmic grouping

Rhythmic Hierarchy


Handel

Wednesday, February 4, 2009
Repeated patterns, groupings, expectancies, and their violations

Ludwig van Beethoven
Bagatelle
Opus 33, no. 5
Global temporal pitch representation (Cariani and Delgutte, 1996)

- **All-order** interspike intervals
- **Population-wide** distribution:
  - All auditory nerve fibers
  - (all CFs, all SRs)

**Predictions**

**Pitch (frequency)** =
the predominant interval or interval pattern

**Pitch strength (salience)** =
the relative fraction of pitch-related intervals in the whole distribution

**Detectability:** A pitch can be heard iff its salience
Neural timing nets

**FEED-FORWARD TIMING NETS**
- Temporal sieves
- Extract (embedded) similarities
- Multiply autocorrelations
- Pitch & timbre matching

**RECURRENCE TIMING NETS**
- Build up pattern invariances
- Detect periodic patterns
- Separate auditory objects by F0
- Metric induction
- Time domain comb filters

\[
S_i(t) \quad S_j(t - \tau) \\
\sum S_i(t_m) S_j(t_m - t)
\]

Time delays present

Time patterns reverberate through delay loops

Recurrent, indirect inputs

Coincidence units

Direct inputs

Input time sequence
Emotion & meaning in music

Psychological functions of music: why we do it
- Perceptual-cognitive interest (formalism, surprise)
- Mood control & emotional expression (expressionism, nostalgia)
- Social functions (religious, athletic, & civic ritual; courtship; dance; group cohesion; shared symbols; group identity)

Sources of meaning: reference and/or construction
The meaning of meaning: semiotics
- External env. associations: linkages w. memories
- Lyrics and their semantics
- Internal associations: body rhythms, patterns
- External musical associations, expectations (e.g. dirge)
- Intrinsic music expectations (harmonic & rhythmic org.)

What cues convey emotional meaning in music?
Figure by MIT OpenCourseWare. After Tramo, M. Science 291, no. 5501 (2001): 54-56.
What we hear:
Deutsch Chapter 4
(Rasch & Plomp)