Music Perception & Cognition

HST 725

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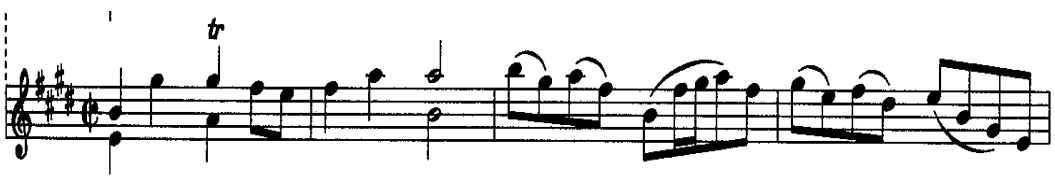


Wednesday, February 4, 2009

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

Johann Sebastian Bach

Organ Triosonata in c minor

Third movement

Un poco Allegro

Texts

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

- Deutsch, D. ed. 1999. The Psychology of Music. San Diego: Academic Press. Required. (MIT Coop)

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

- Handel, S. 1989. Listening: an Introduction to the perception of Auditory Events. MIT Press. Recommended. (MIT Press Bookstore)
- Levitin, D. 2006. This is Your Brain on Music. Required. (MIT Coop, optional)

- McAdams & Bigand. 1993. Thinking in Sound: The Cognitive Psychology of Human Audition. Oxford. Recommended. Not at the Coop.
- Aello, R. ed. 1994. Musical Perceptions. OUP. Recommended, not at the Coop.
- Moore BCJ. 2003. An Introduction to the Psychology of Hearing, Fifth Ed.. San Diego: Academic Press. Recommended. At the Coop.

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)

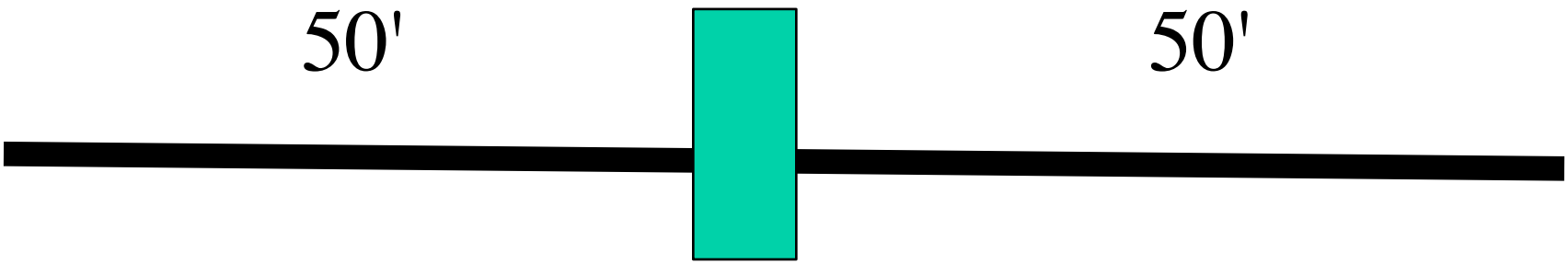
Psychoacoustics, psychology (listener's response, incl. our own)

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



5-10' Break
Stretch
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

V. 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 w. 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

Music and the cerebral cortex. Overview of functional role of cortex in music perception & cognition. Results of imaging and lesion studies. Hemispheric asymmetries. Neurological theory of psychological functions.

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

• Clinical issues. Music exposure and hearing loss. Music perception and hearing impairment. Music and hearing aids. Music perception by cochlear implant users. Possible technological remedies.

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, spatia 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%)**

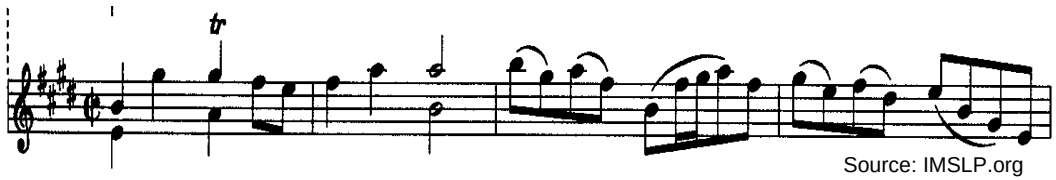
A relevant paper will be chosen, presented (10-15'), and discussed by the class. This can be one of the papers on the reading list or any paper that you feel is important or insightful.

- **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 pro ject (e.g. psychological or physiological experiment, computer model/simulation) related to the psyc hology 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 c lass. I will be happy to read an d give comment on outlines and drafts at any stage of preparation.



Source: IMSLP.org

An Introduction to Music: Sound unfolding in time

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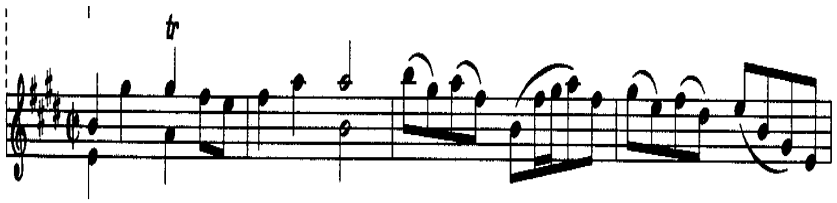
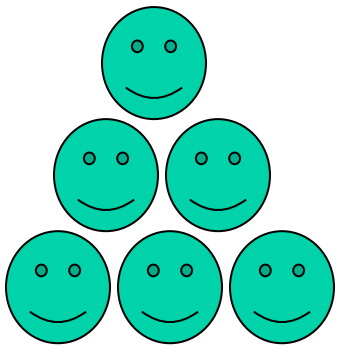
Sound unfolding in time: an introduction to music

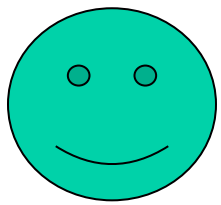
- Music: a bird's eye view; provisional definition
- Ubiquity of music: Nature and nurture
- Sound unfolding in time
  - Horizontal dimension (time, sequential sounds)
    - Melody (Temporal patterns/sequences of pitches)
    - Chord progressions, key modulations (Temporal patterns/ sequences of pitch 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



relation





Psychology of music examines relations between music and mind.

Music is half of this relation.

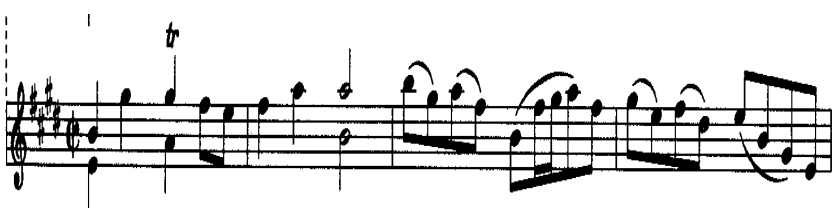
Mind has different facets:

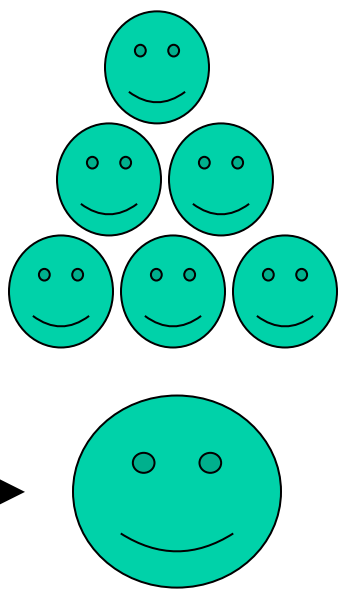
1st person experience
3rd person overt behavior
Underlying neural activity
Functional organization of informational processes

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

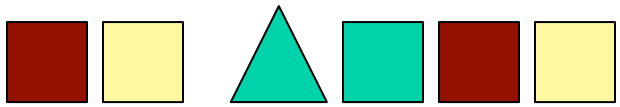
Horizontal and vertical dimensions

Tonal quality
(pitch, spectrum)

Time (beats, seconds)

successions of events, changes

Horizontal and vertical dimensions

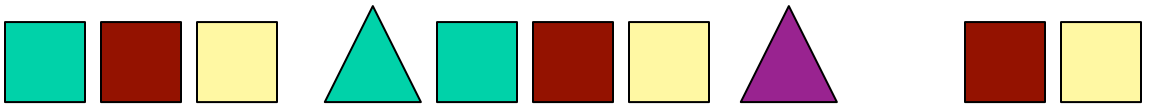


Tonal quality
(pitch, spectrum)

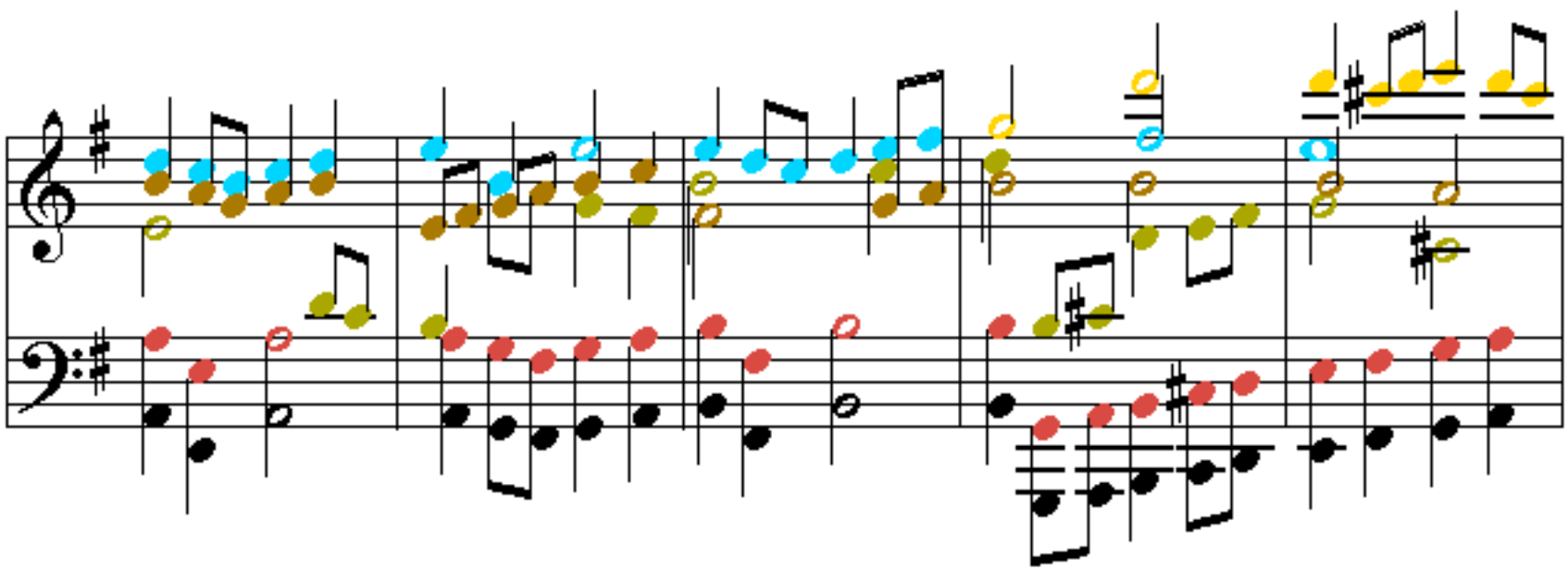
Time (beats, seconds)

successions of events, changes

Horizontal and vertical dimensions



Tonal quality
(pitch, spectrum)



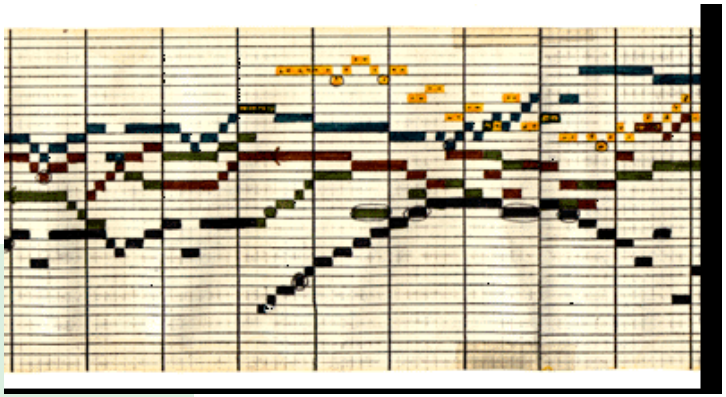
http://www.well.com/user/smalin/compare.htm

Courtesy of Stephen Malinowski. Used with permission.

Time (beats, seconds)

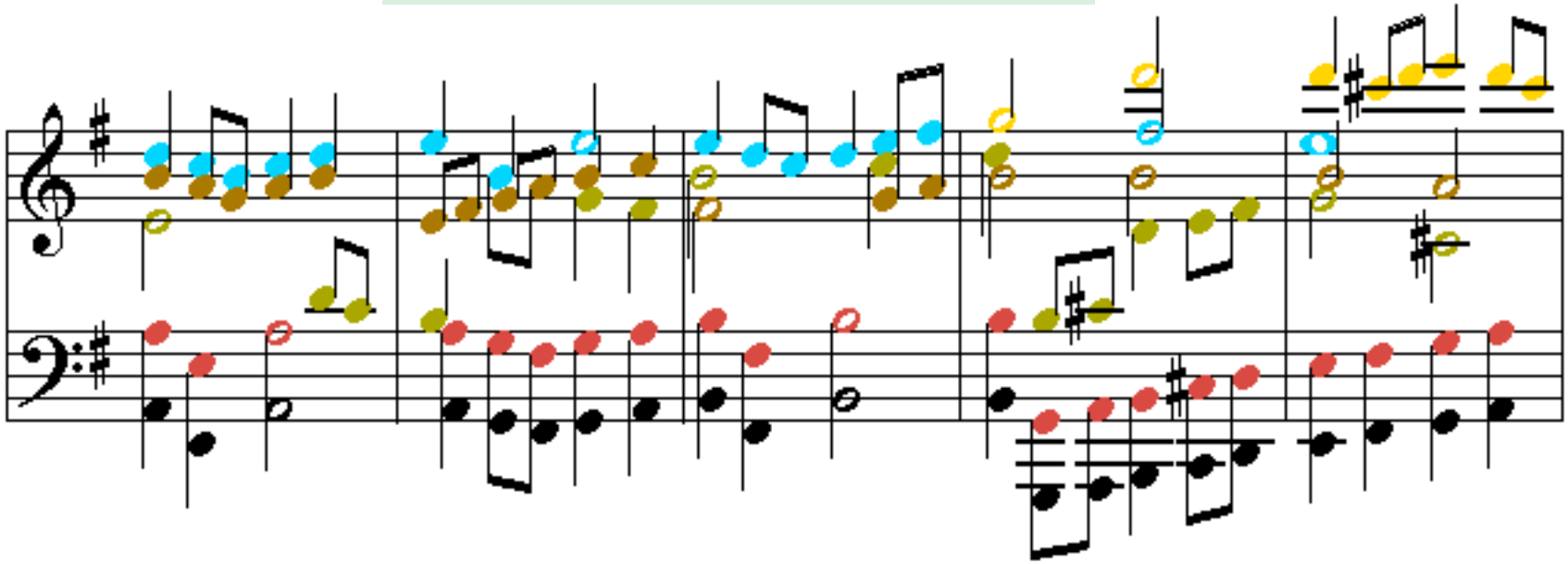
successions of events, changes

Horizontal and vertical dimensions



Tonal quality
(pitch, spectrum)

Density
Complexity
independent trajectories



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

Time (beats, seconds)

Horizontal dimension (time)

Temporal patterns and sequences of sound-changes

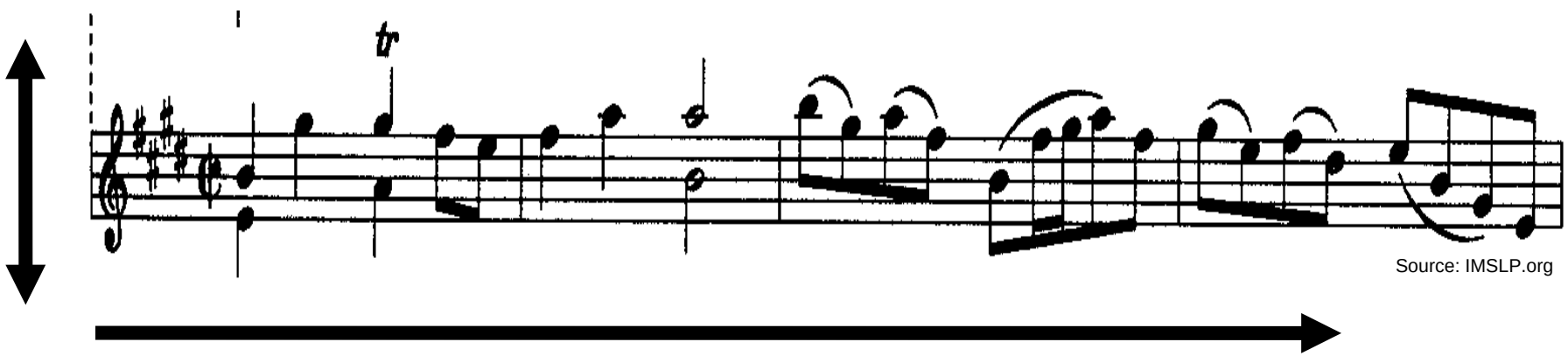
Melody: temporal patterns of pitches

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

Horizontal dimension involves temporal context & memory
Build-up of representations and expenctancies
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

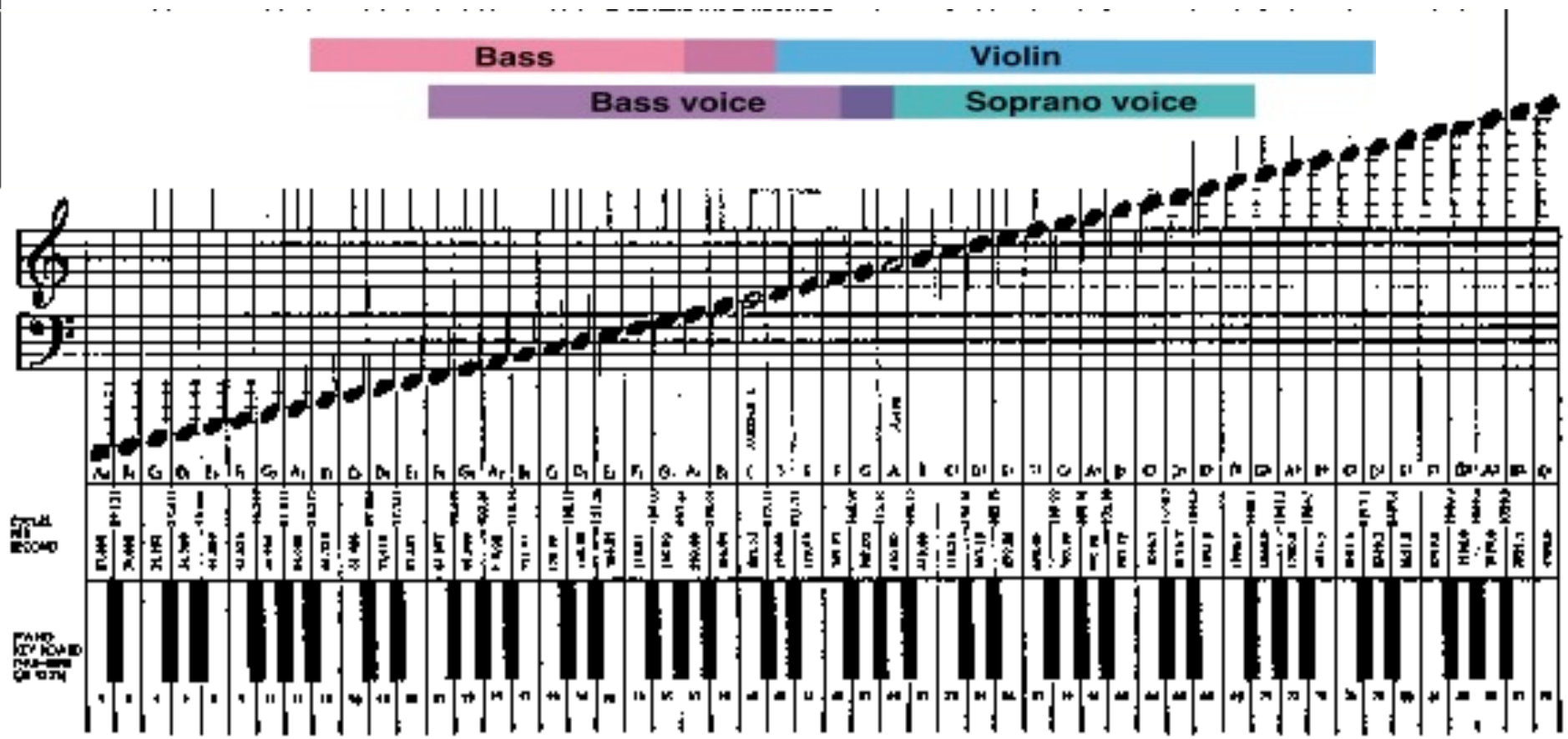
- **Mnemonics** Familiarity
- **Hedonics** Pleasant/unpleasant
- **Semantics** Cognitive & emotional associations

Frequency ranges of (tonal) musical instruments

8k
6
5
4
3
2

> 6 kHz

2.5-4 kHz



27 Hz

110 Hz

262 Hz

440 Hz

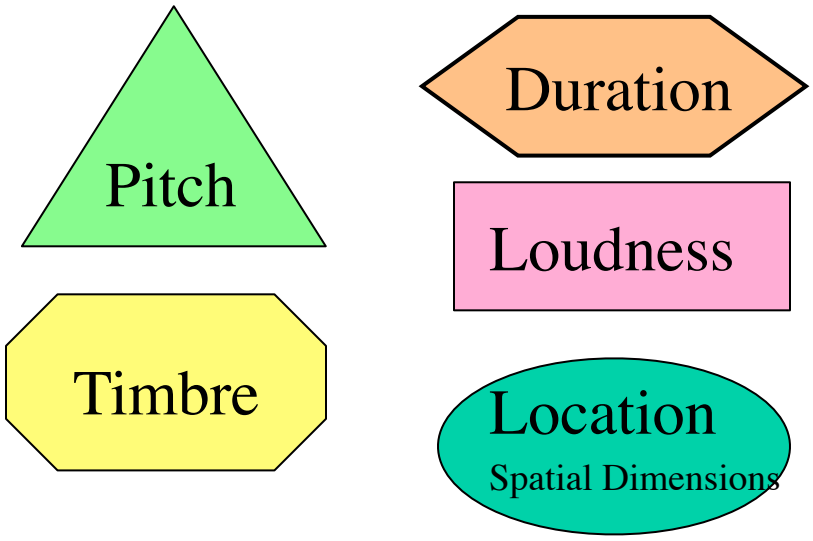
880 Hz

4 kHz

Dimensions of auditory objects

Auditory qualities and their organization

Objects: Quasi-stationary assemblages of qualities



FUSION/SEPARATION

Common onset & harmonic structure => fusion

Different F0s, locations, onset => separation

POLYPHONY

Dimensions of event perception

Unitary events & their organization

Events: abrupt perceptual discontinuities

TEMPORAL EVENT STRUCTURE

Timing & order (metric, sequence)

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)

Auditory thalamus

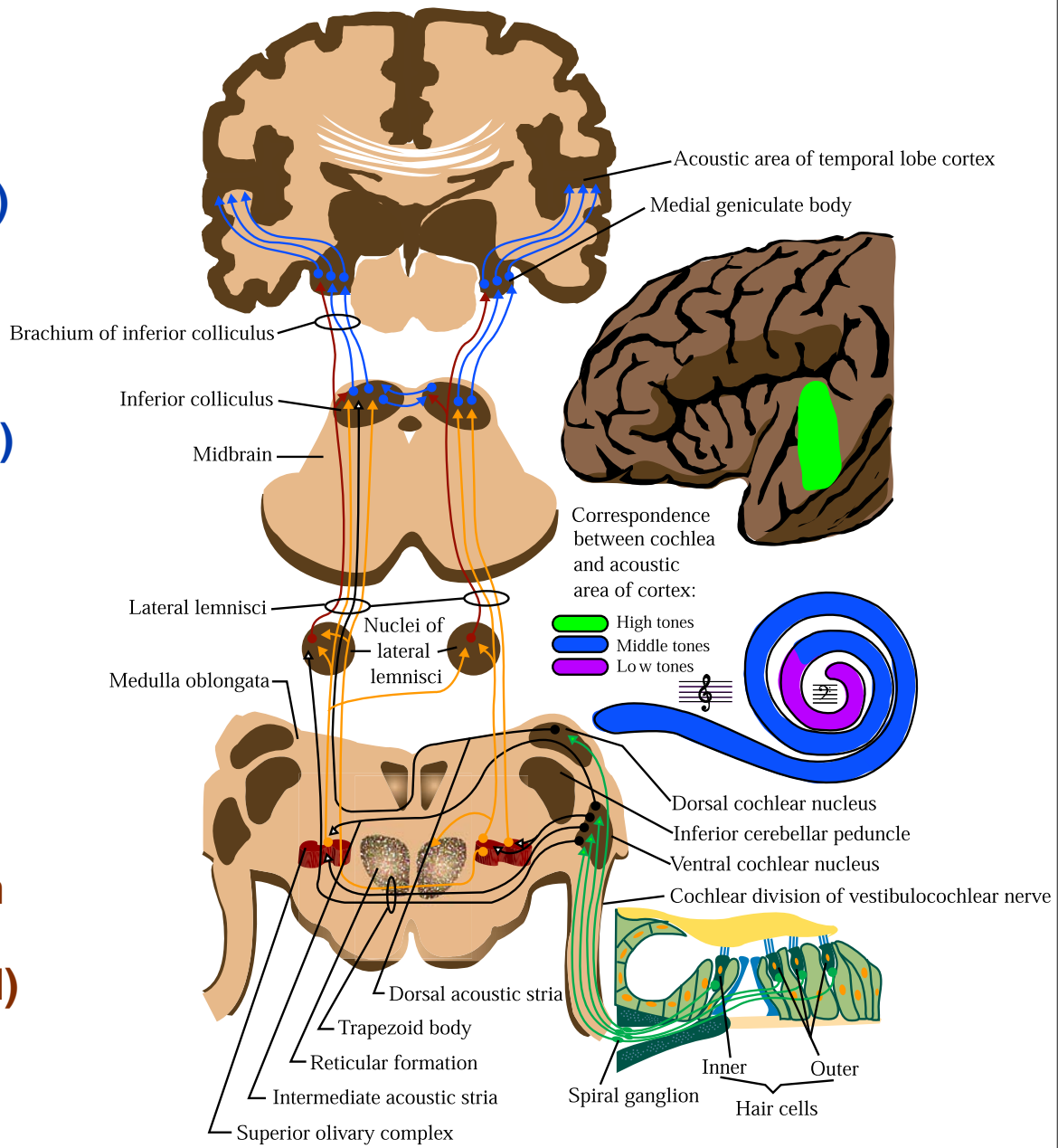
500k — Inferior colliculus (Auditory midbrain)

Lateral lemniscus

Auditory brainstem

30k — Auditory nerve (VIII)

3k — Cochlea



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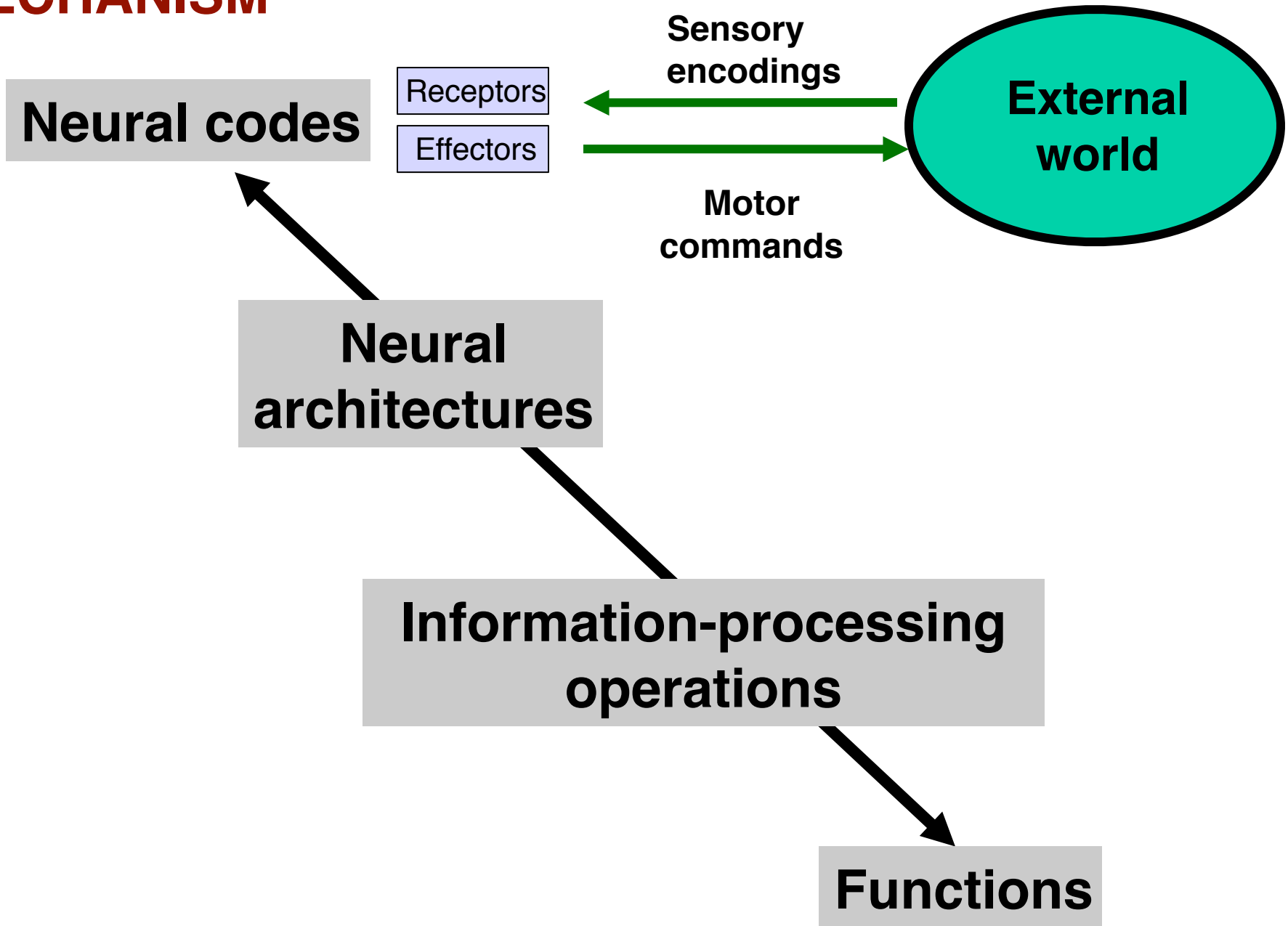
MECHANISM


Sensory encodings
Receptors
Effectors
External world
Neural codes
Motor commands
Neural architectures
Information-processing operations
Functions

MECHANISM

Neurophysiology
Neurocomputation

Music cognition
Music theory

Neurophysiology Neurocomputation	Music cognition Music theory
Neural responses	Schemas, grammars
Neural codes	Event structures
Neuroanatomy	Tonal hierarchies
Psychoacoustics	Memory
Reverse-engineering	Aesthetics, hedonics
Explaining pitch	Pitch as a primitive

Visual grouping

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

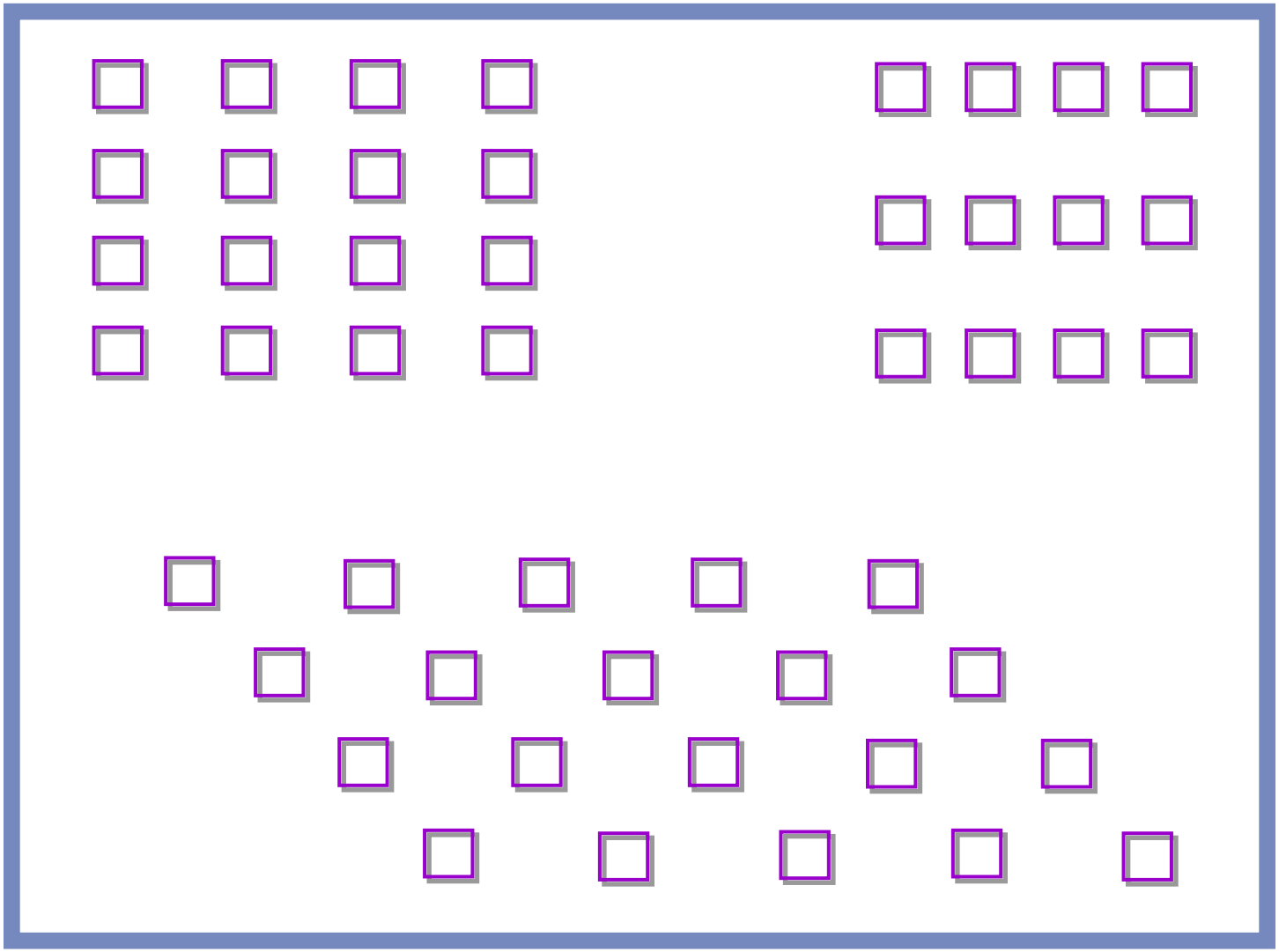
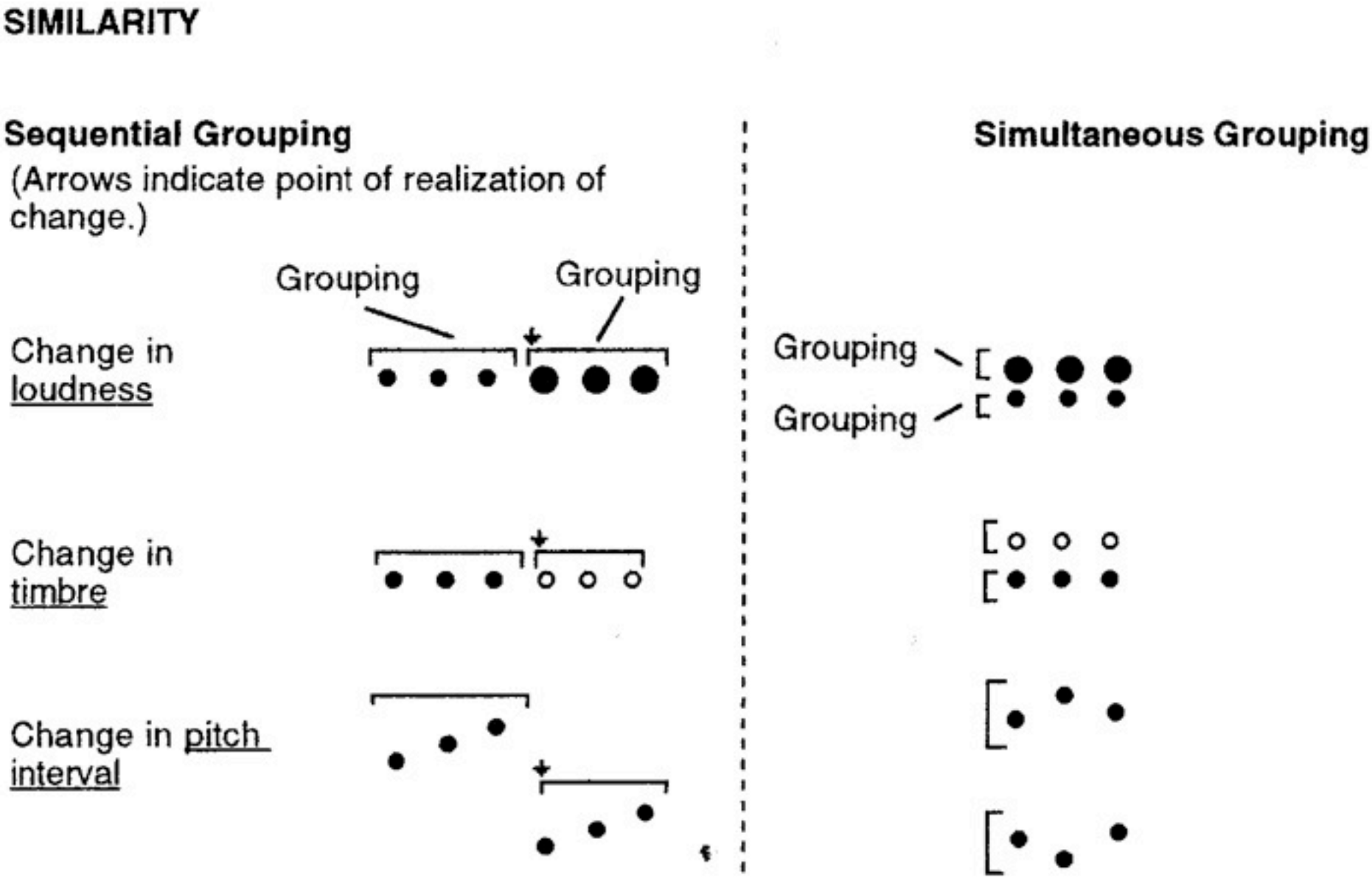


Figure by MIT OpenCourseWare.

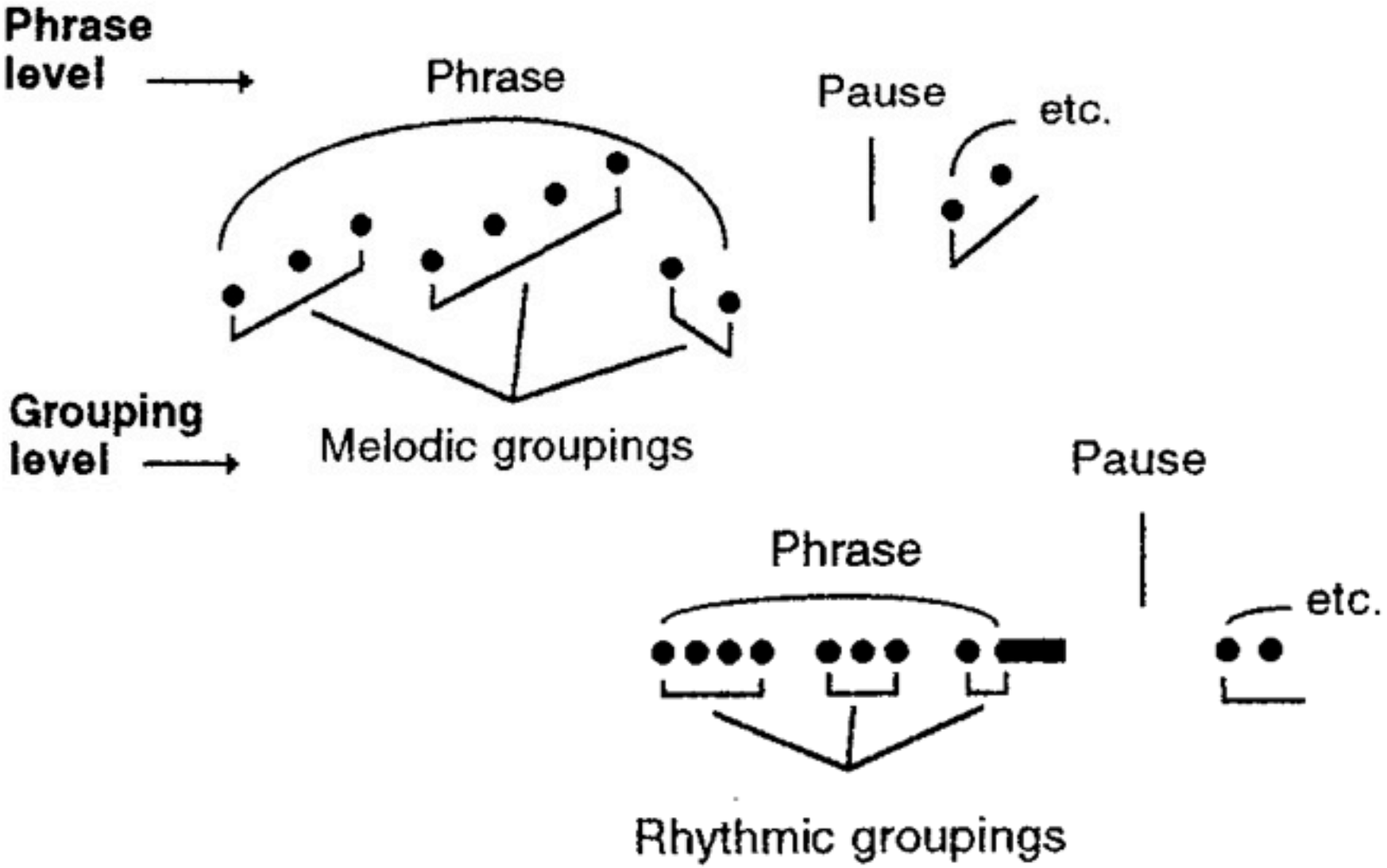
Acoustical grouping

(Snyder, Music & Memory)



Source: Snyder, Bob. *Music and Memory*. Cambridge, MA: MIT Press, 2000. Courtesy of MIT Press. Used with permission.

Melodic grouping & rhythmic grouping



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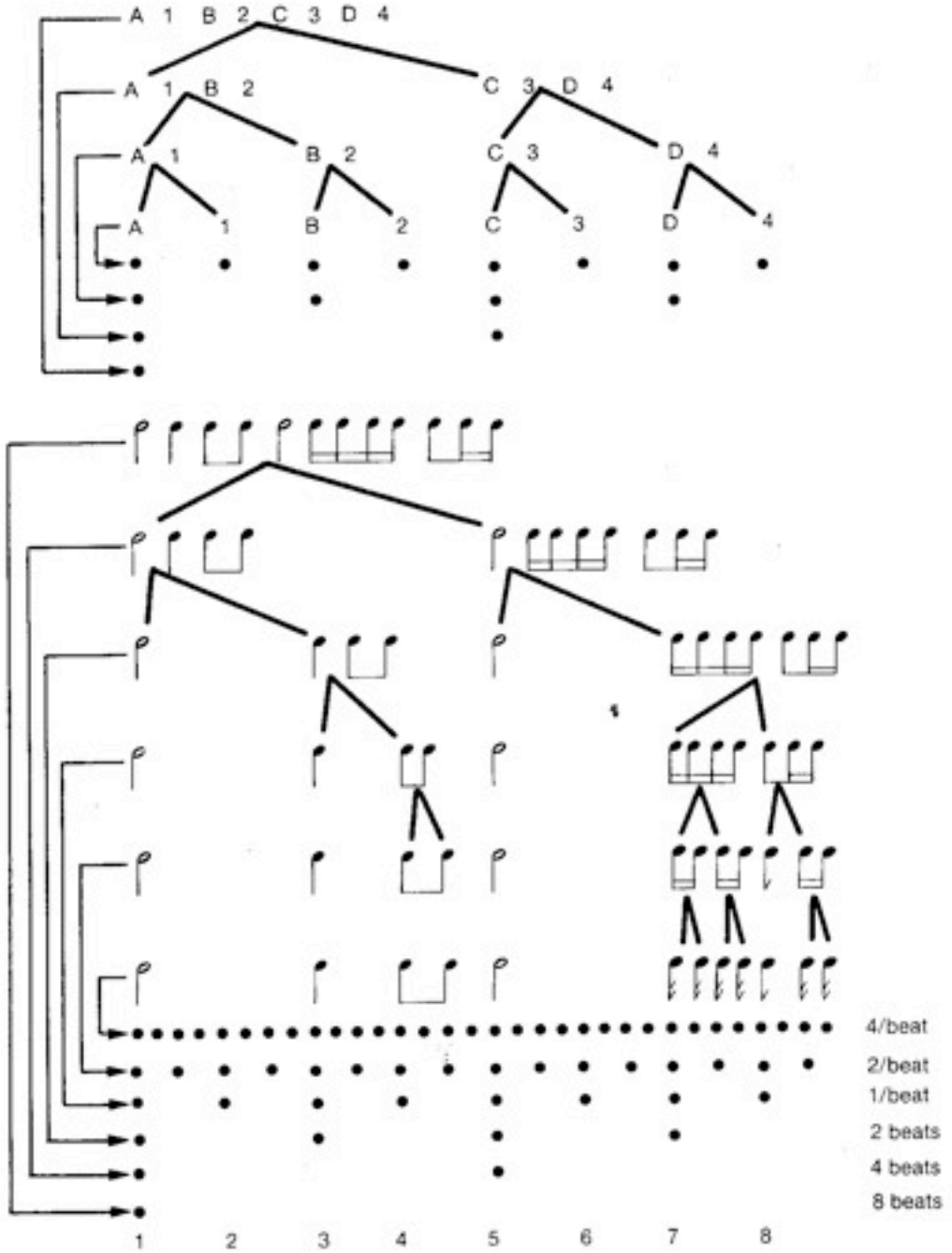
Rhythmic Hierarchy



Source: Handel, S. *Listening: an Introduction to the Perception of Auditory Events*. Cambridge, MA: MIT Press, 1989. Courtesy of MIT Press. Used with permission.

Handel

Repeated patterns, groupings, expectancies, and their violations

Ludwig van Beethoven

Bagatelle

Opus 33, no. 5

Global temporal pitch representation (Cariani and Delgutte, 1996)

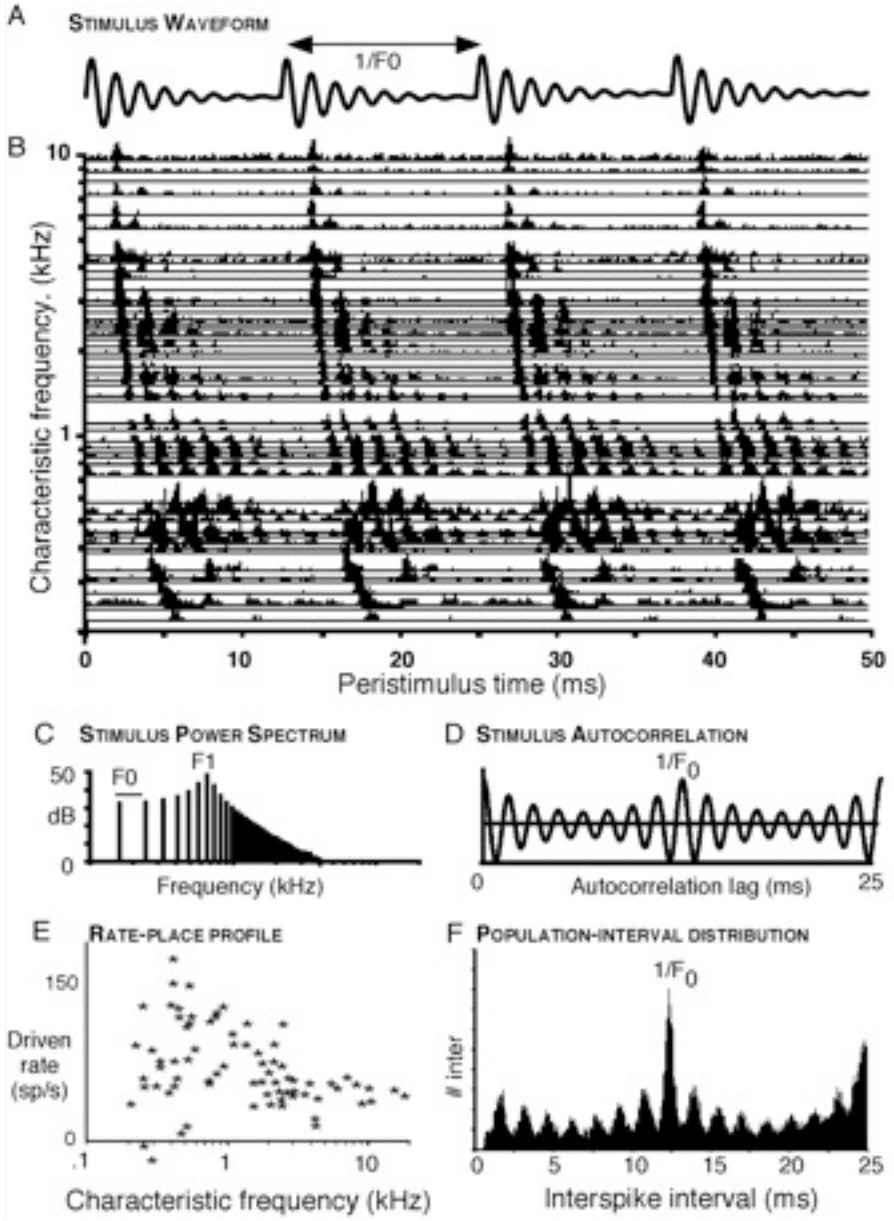
- **All-order** interspike intervals
- **Population-wide** distribution:
  - –**All** auditory nerve fibers
  - –(all CFs, all SRs)

Predictions

Pitch (frequency) =
the predominant interval
or interval pattern

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

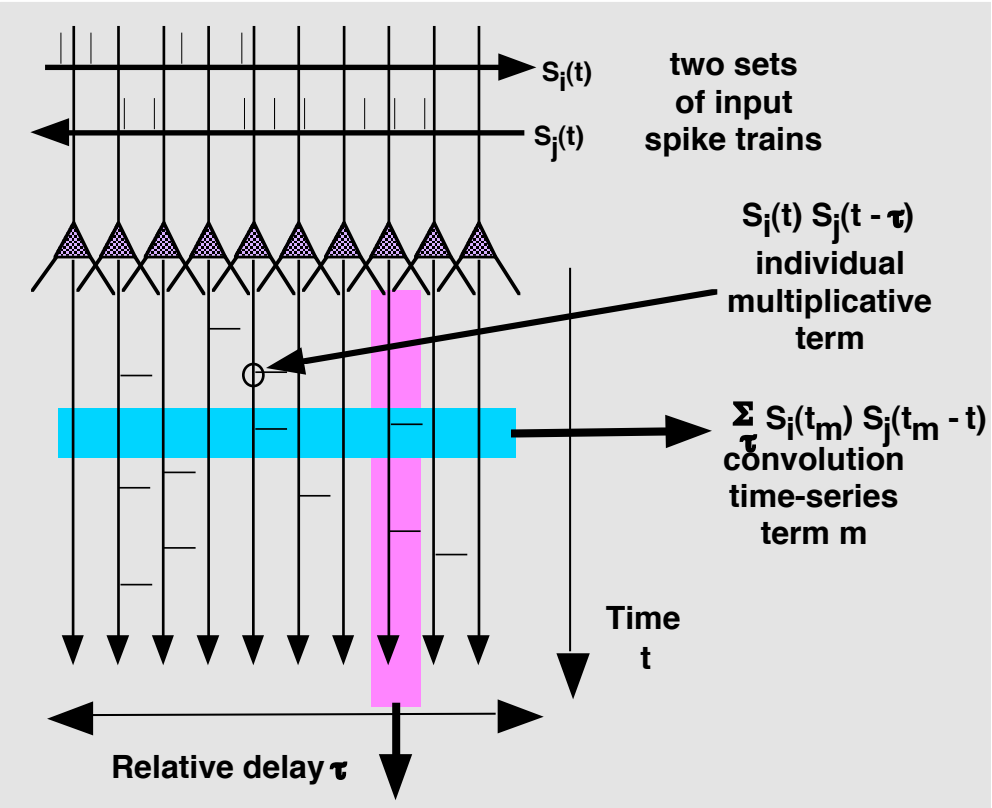
Detectability: A pitch can be heard iff its salience



Neural timing nets

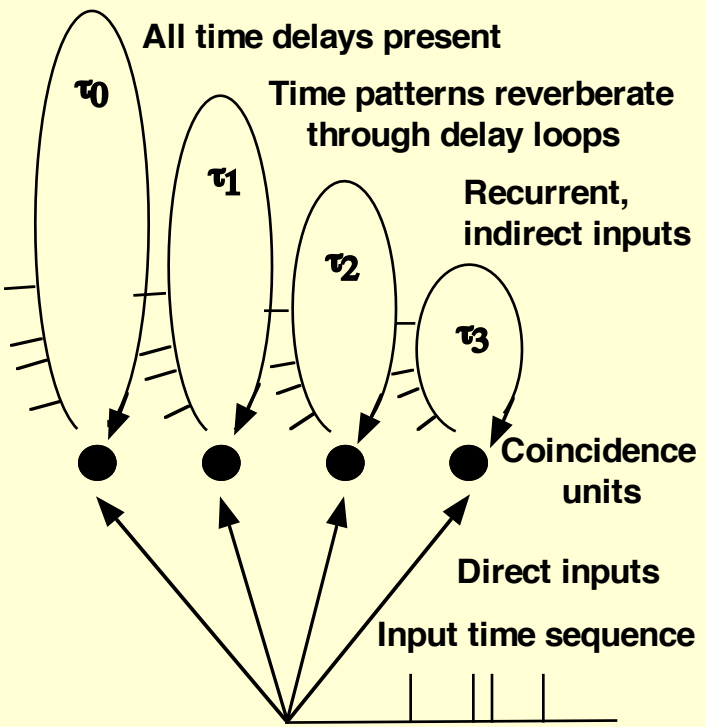
FEED-FORWARD TIMING NETS

- Temporal sieves
- Extract (embedded) similarities
- Multiply autocorrelations
- Pitch & timbre matching



RECURRENT TIMING NETS

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



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?

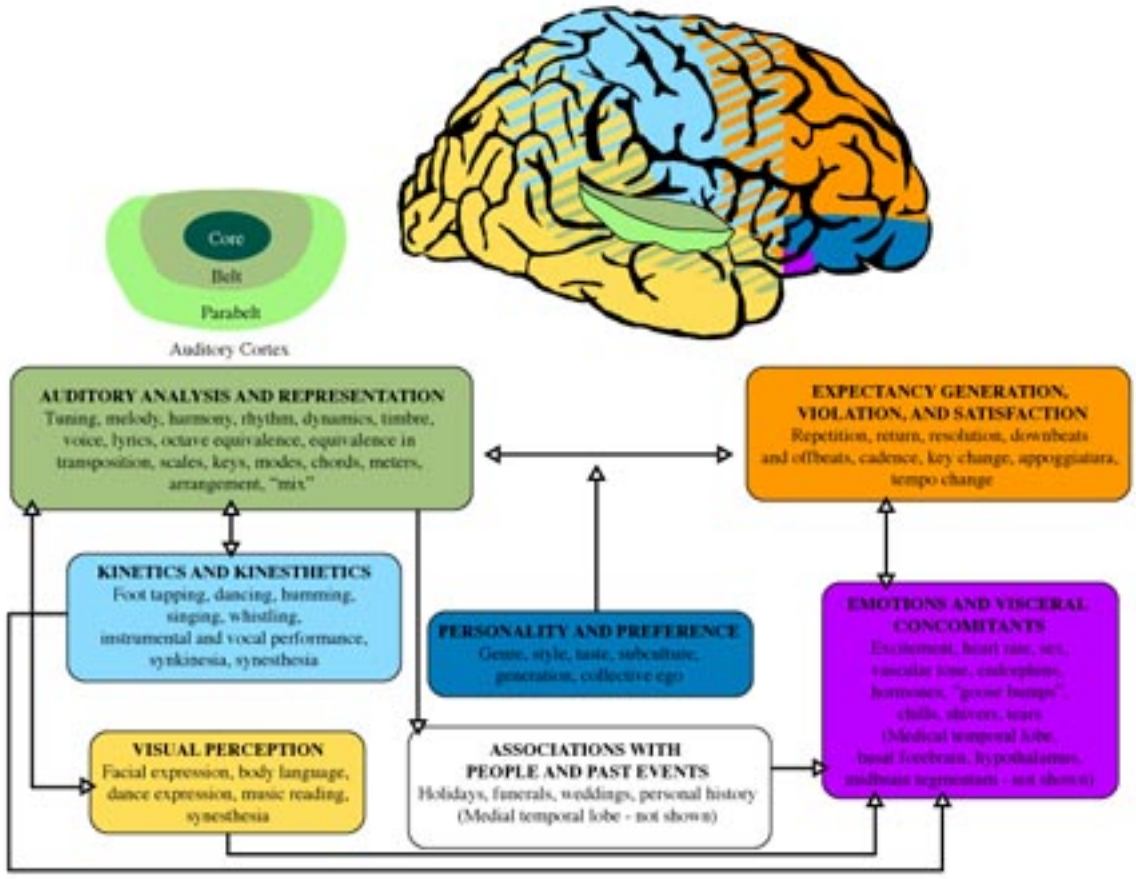


Figure by MIT OpenCourseWare. After Tramo, M. Science 291, no. 5501 (2001): 54-56.

Reading for Thursday, Feb. 8

What we hear:
Deutsch Chapter 4
(Rasch & Plomp)

HST.725 Music Perception and Cognition

Spring 2009