Clap along

How did you know when to clap?

beat or tactus

Tactus: a basic pulse

- Rate at which we spontaneously tap while listening to music.
- Evenly or regularly spaced.
- Typically falls in the range between 0.6 and 0.75 seconds (80 to 100 events per minute).
- Commonly coincides with the beat rate but remains an undifferentiated pulse.

Beat:

- A recurring moment when tone onsets are more expected.
- Strong - weak differentiation.
- Occurs within a repeating pattern of beats - *meter.*

How do we identify them?

Most are highlighted or accented

- Clear onsets
- Relatively loud
- Notes played are usually harmonically important
- Low down in the texture, the bass line is bringing them out

- Quick

Tap along

We readily insert additional beats and form a metrical structure

Even when the rest of the information doesn’t match/support it

Our tapping is not merely responsive

How do you know it's the beginning of the bar?

- Repetition / Parallelism
- Loudest
- Longest
- Lowest
- Strong base notes
- Cadences
- Suspension (on strong beat)
- Alternating strong / weak

Strong beat early

Formalised in Lerdahl and Jackendoff

Human perception of musical structure

Digital Signal Processing with Computer Music

Dr Neta Spiro

ns319@cam.ac.uk

Human perception of musical structure

- Rhythm and time
  - Metrical structure
  - Time and memory
- Musical pitch in cognition

How do we recognise the metrical structure?

- Building on first beat identification
- Hierarchy of beat strength in the bar
  - e.g. binary vs. ternary
- Relationship between bars

Temporal Awareness

How are we aware that time has passed?

→ Through the perception of CHANGE

Temporal Awareness

Change may be:

- External: aware of events occurring in the environment (Heraclitus, Plato)
- Internal: aware of changes in our own proprioceptive state (James 1890)
- Mental: psychological awareness of duration (Bergson 1911, Langer 1953)

Temporal Awareness

Or, "Events are perceivable; time is not"

(Gibson 1975)

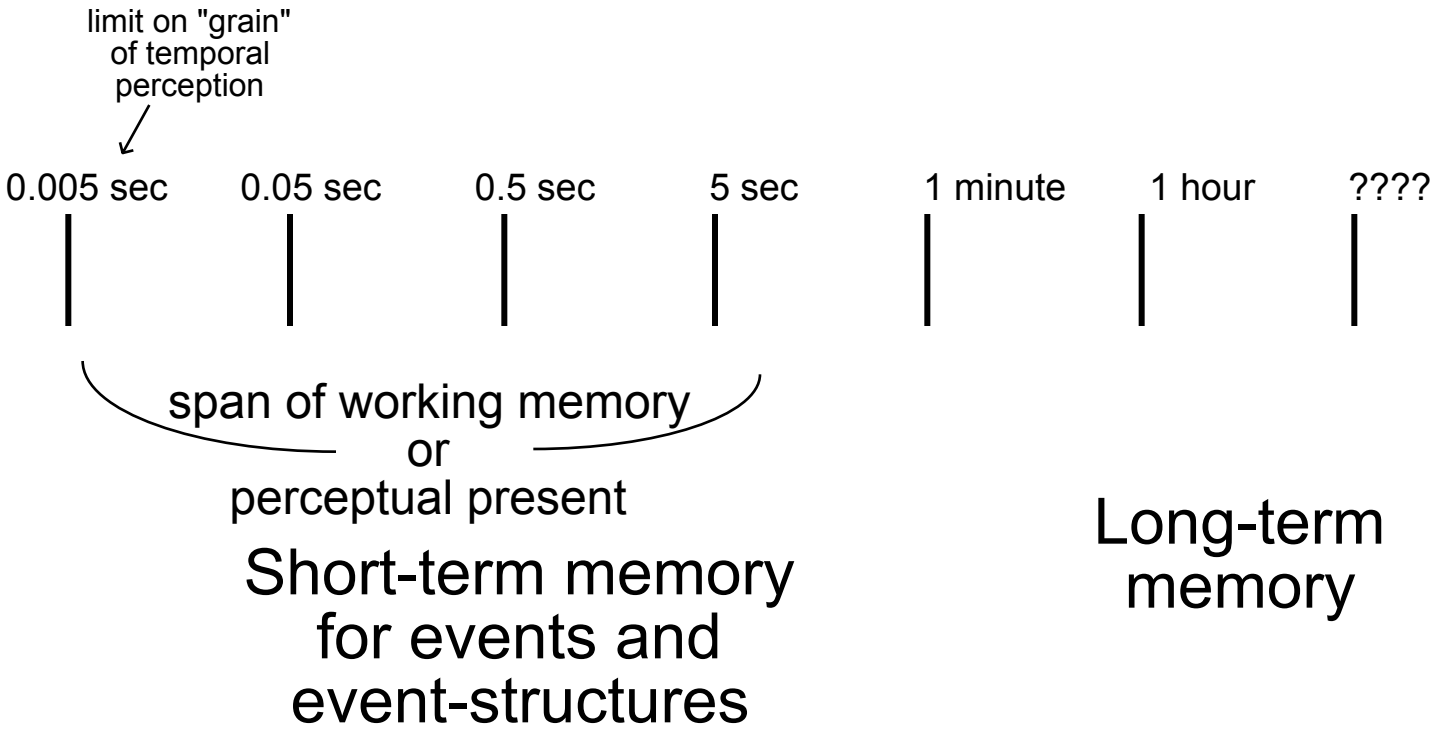
→ The events that are most salient in music perception are sound onsets.

Some constraints on our experience of things (music) happening in time

- Temporal resolution
- Engagement
- Amount of processing
- Schemata
- Predictions
- Memory
- Complexity
- Similarity

Time and Memory

The perception of time



Time and Memory

"The experience of a duration of a [time] interval is a construction formed from its 'storage size' - as storage size increases the experience of duration increases."

Ornstein, 1969, p. 42

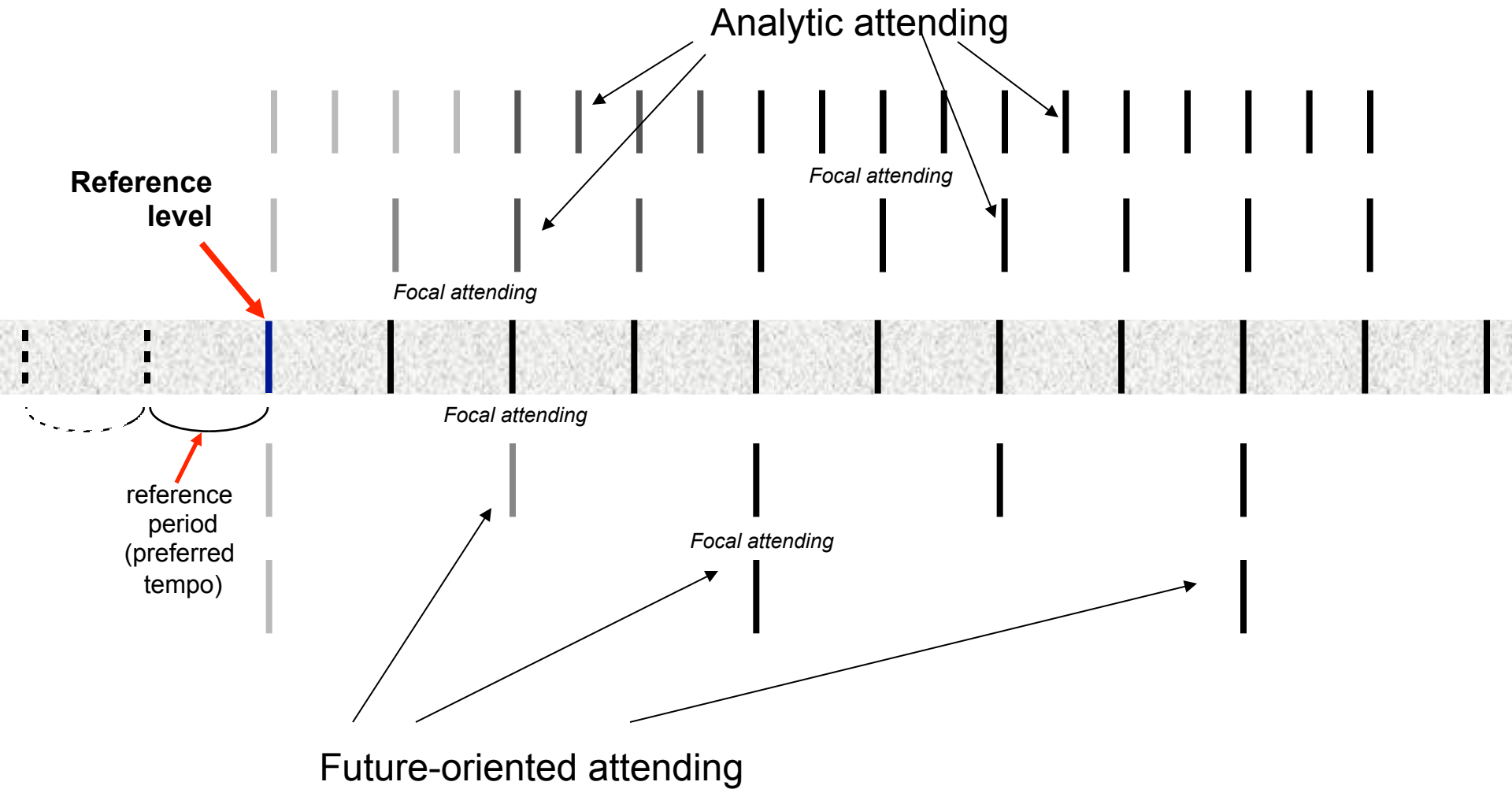
Ornstein, R.E., (1969), *On the Experience of Time*, (Harmondsworth: Penguin).

Time and Memory

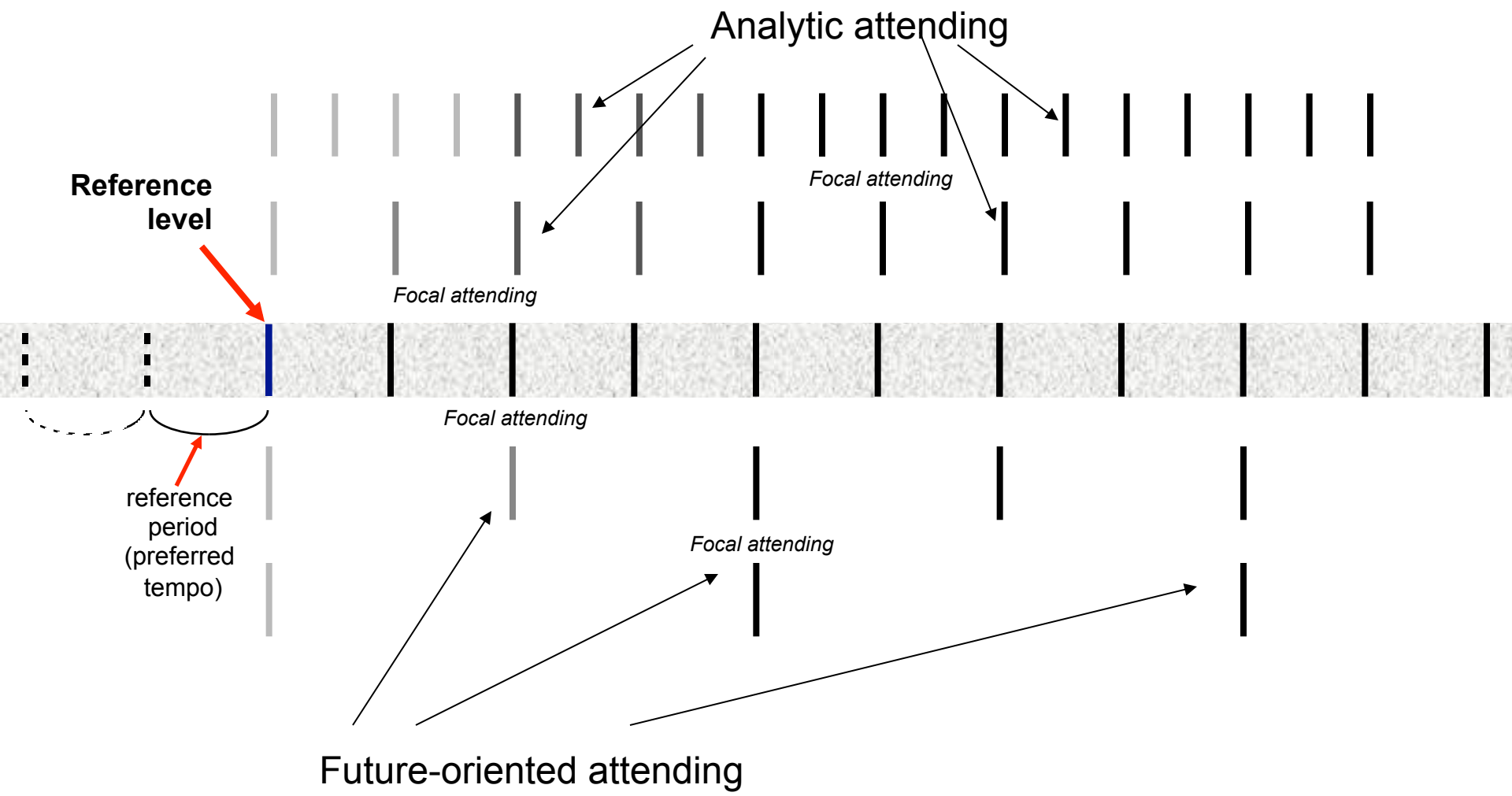
- “Storage size”
  - Rate of events
  - Attentiveness
  - Other events

Time and Memory

Dynamic Attending (Jones 1986, Jones and Boltz 1989)



Metre

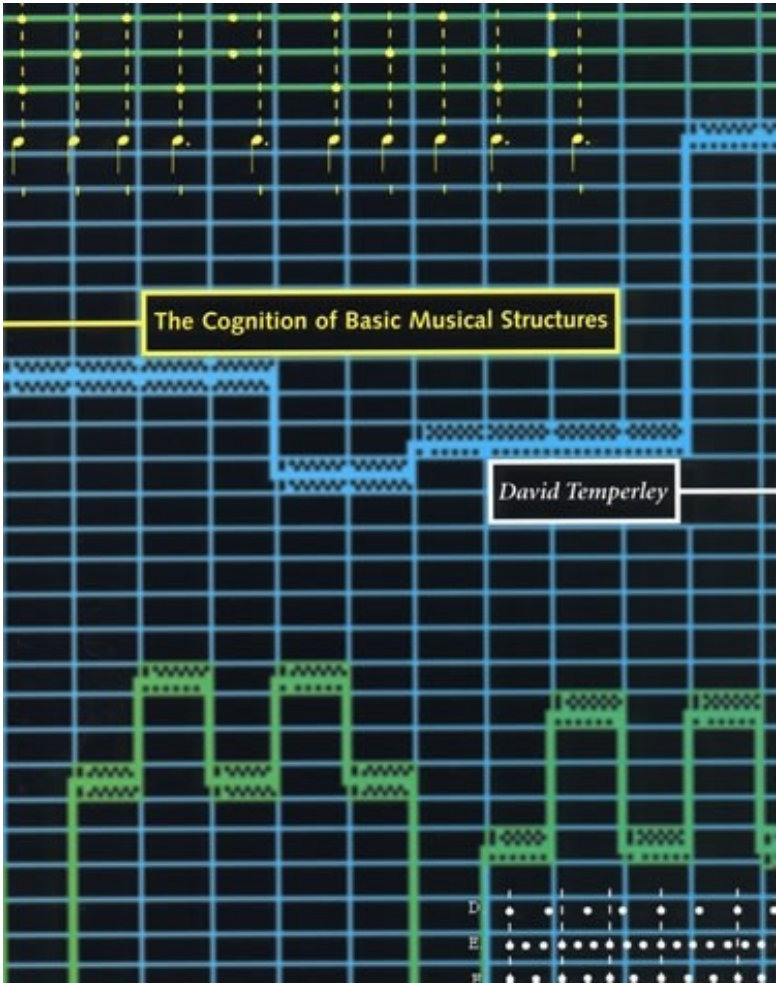

Analytic attending
Reference level
Focal attending
Focal attending
Focal attending
Focal attending
reference period (preferred tempo)
Future-oriented attending

Four ‘levels of analysis’ Lerdahl and Jackendoff

- Metrical
  - Based on principles of binary & ternary hierarchy
  - Strictly limited in terms of the levels to which the hierarchy might extend,
- Grouping
  - Structure largely predicated on events at the level of the musical surface
  - Includes groups of many sizes, including the “phrase”
  - Chunking

Four ‘levels of analysis’

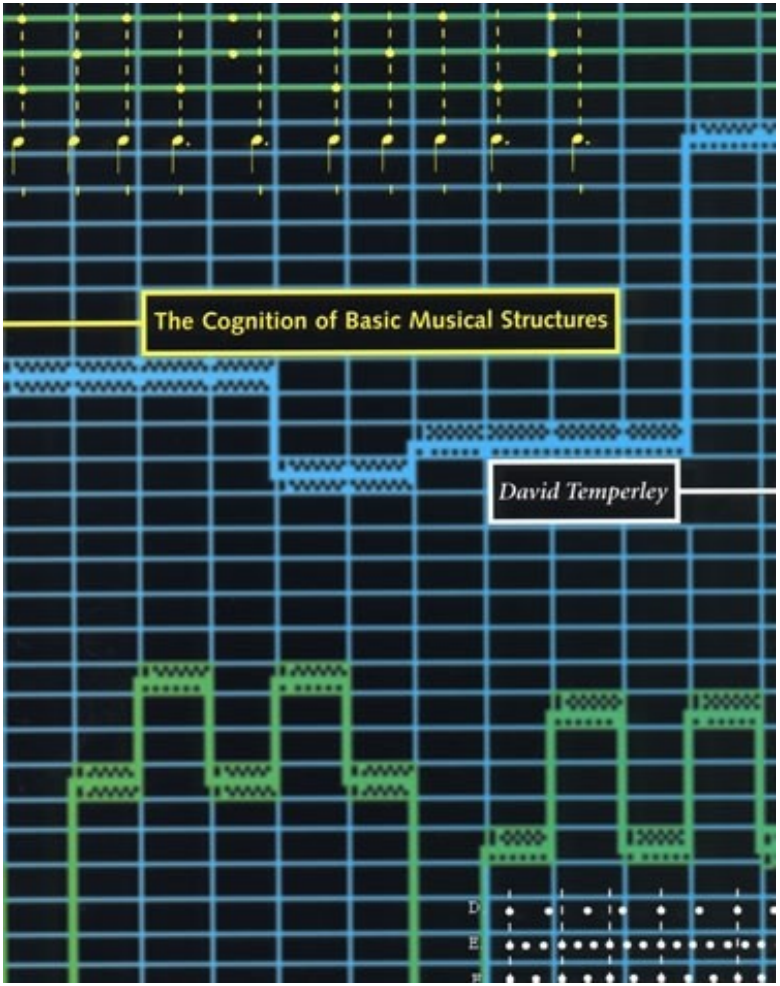
- Metrical and Grouping Rules
  - Largely derived from musical surface
  - More determined by the musical stimulus and general aspects of our perceptual systems than by any specifically (schematically learned) musical considerations,
  - Though musical considerations can play a role (esp. in grouping).



Temperley

A preference rule system evaluates many possible interpretations and chooses the one that best satisfies the rules for meter, phrase structure, contrapuntal structure, harmony, and key, as well as pitch spelling.

Preference rule systems not only show how musical structures are inferred, but also shed light on other aspects of music: musical ambiguity, retrospective revision, expectation, and music outside the Western canon (rock and traditional African music).



Temperley

Proposes a framework for the description of musical styles based on preference rule systems and explores the relevance of preference rule systems to higher-level aspects of music, such as musical schemata, narrative and drama, and musical tension.

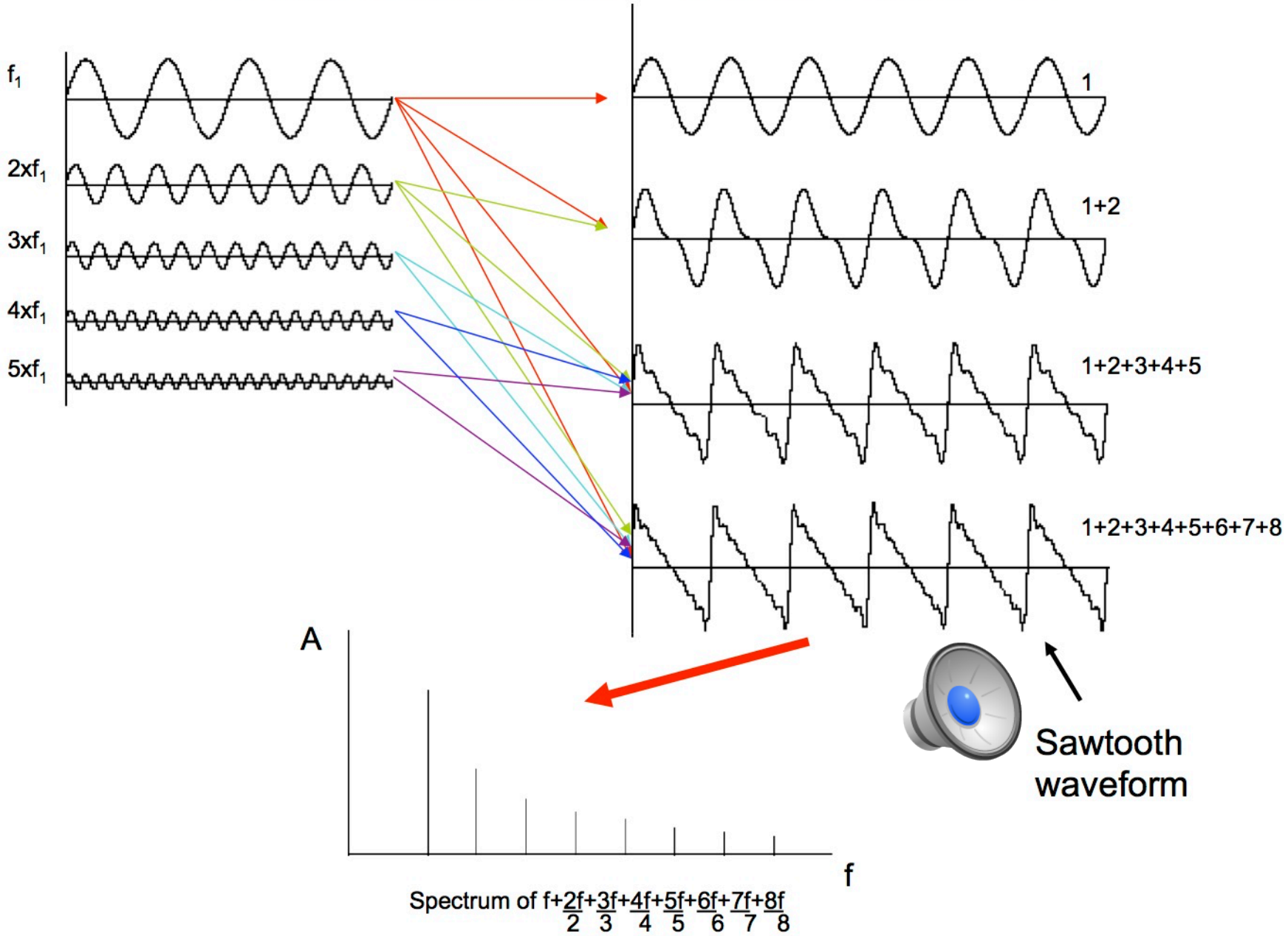
Rhythm and time
Summary

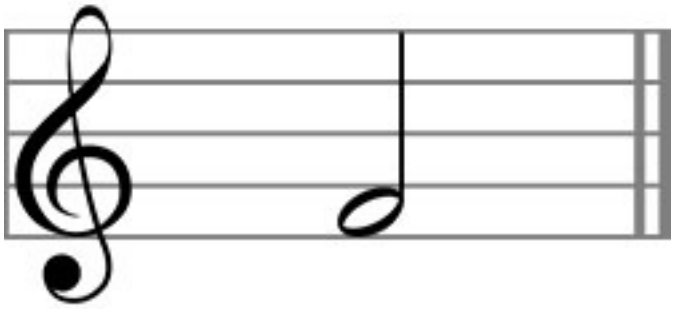
- We readily (and quickly) hear and respond to a pulse in music (and other info)
- We readily hear a metrical structure in music (and other info)
- For both of these we use cues in the music
- Together they are part of a multi-levelled structure

- We can generate our own pulse independently of music or with it
- Theorists such as Jones and Lerdahl and Jackendoff have summarised patterns of behaviour and some theories

Musical pitch in cognition

Complex waveforms - additive synthesis





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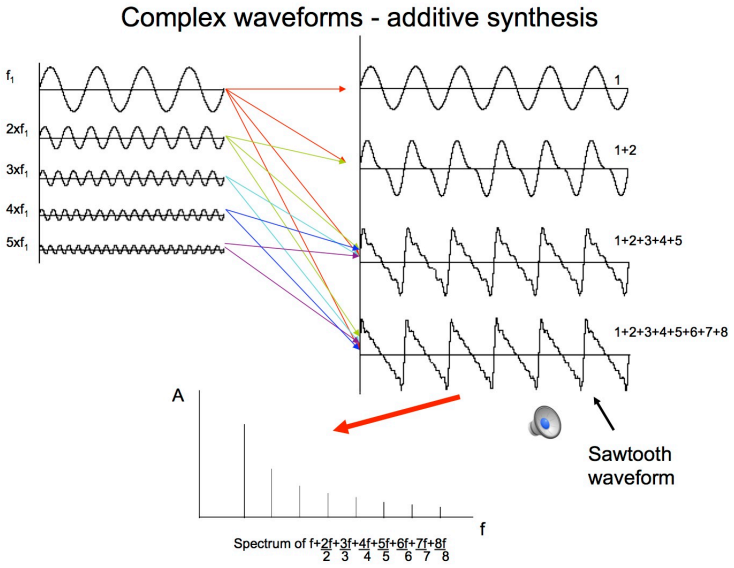
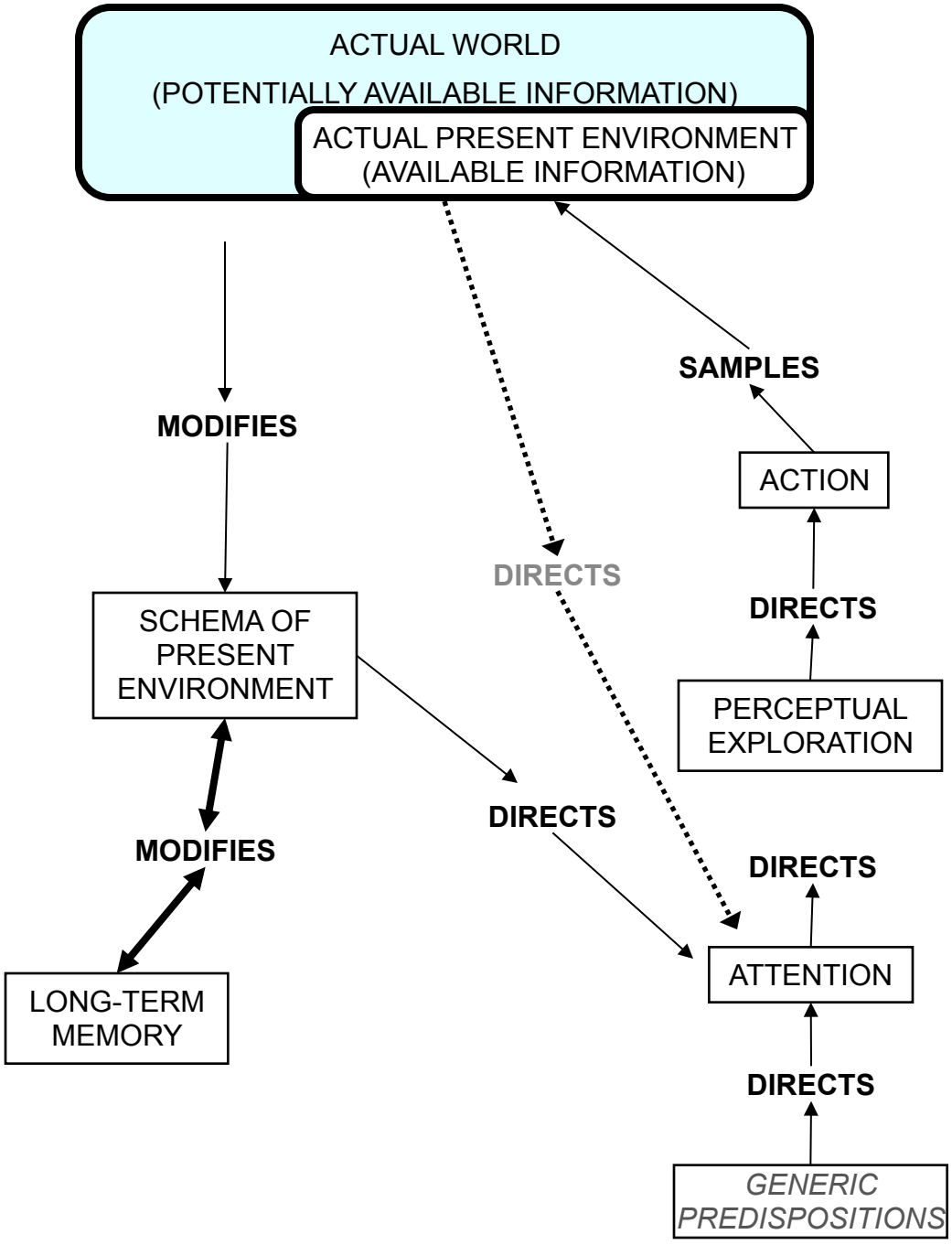

Complex waveforms - additive synthesis
f1
2xf1
3xf1
4xf1
5xf1
1
1+2
1+2+3+4+5
1+2+3+4+5+6+7+8
A
f
Spectrum of f+2f+3f+4f+5f+6f+7f+8f
2 3 4 5 6 7 8
Sawtooth
waveform

- How do we learn pitch relationships and functions?
  - Inherent characteristics of the frequencies we hear?
  - Proportion of time you hear pitch relationships and associated functions?
  - Long term memory?
  - Short term and on the fly?


ACTUAL WORLD
(POTENTIALLY AVAILABLE INFORMATION)
ACTUAL PRESENT ENVIRONMENT
(AVAILABLE INFORMATION)
SAMPLES
MODIFIES
ACTION
DIRECTS
DIRECTS
SCHEMA OF
PRESENT
ENVIRONMENT
PERCEPTUAL
EXPLORATION
DIRECTS
MODIFIES
DIRECTS
ATTENTION
LONG-TERM
MEMORY
DIRECTS
GENERIC
PREDISPOSITIONS

Auditory Scene Analysis

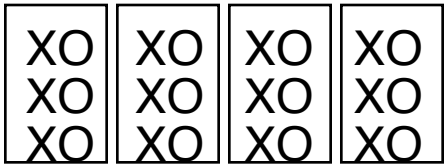
- What do we do when we hear something as a melody?

Figures presented

XO XO XO XO
XO XO XO XO
XO XO XO XO

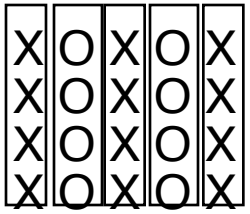
law of proximity

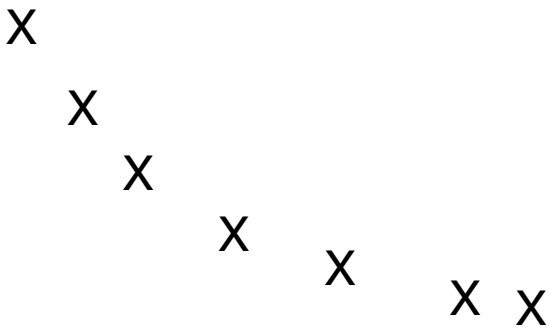
Figures perceived



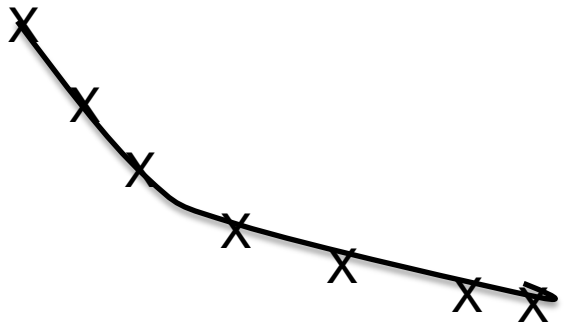
X O X O X
X O X O X
X O X O X
X O X O X

law of similarity



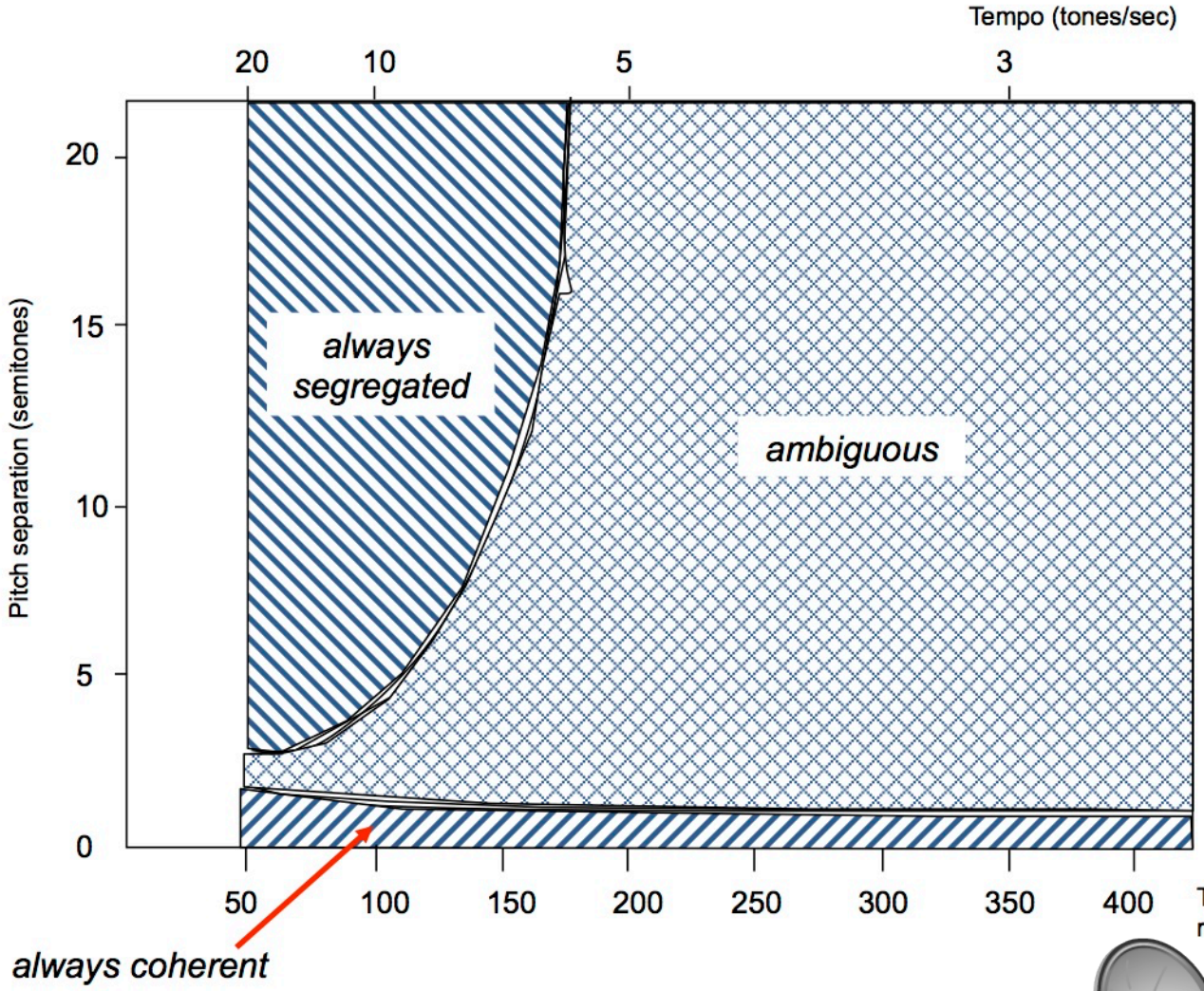


law of good continuation

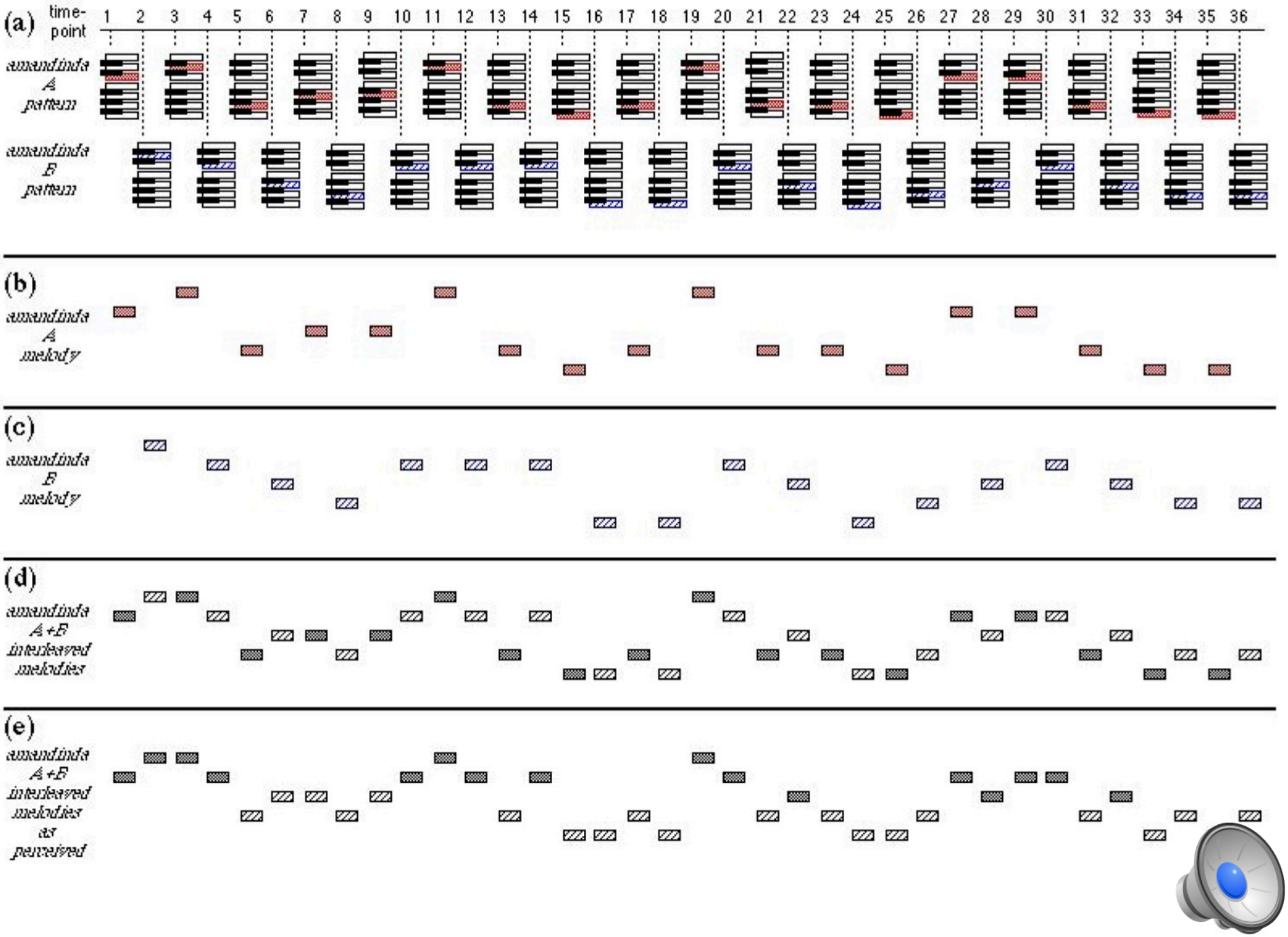


The formation of auditory streams: interaction of rate of occurence and pitch separation

pitch range divergence



speed change


(a)
time-point
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
amandinda A pattern
amandinda B pattern
(b)
amandinda A melody
(c)
amandinda B melody
(d)
amandinda A+B interleaved melodies
(e)
amandinda A+B interleaved melodies as perceived

Auditory scene analysis

- '…is the process whereby all the auditory evidence that comes, over time, from a single environmental source is put together as a perceptual unit' (Bregman, 1993).

Auditory scene analysis

- Acoustical
- Psychological
  - **Psychoacoustical:** primarily concerned with the ways in which our auditory sensory apparatus (outer, middle and inner ear and associated neural structures) transforms acoustical information into the 'language of the brain', neural impulses.
  - **Cognitive**: more concerned with the ways in which this neural information comes to have a functional significance for us.

Cognitive approaches to pitch

Cognitive structuralism

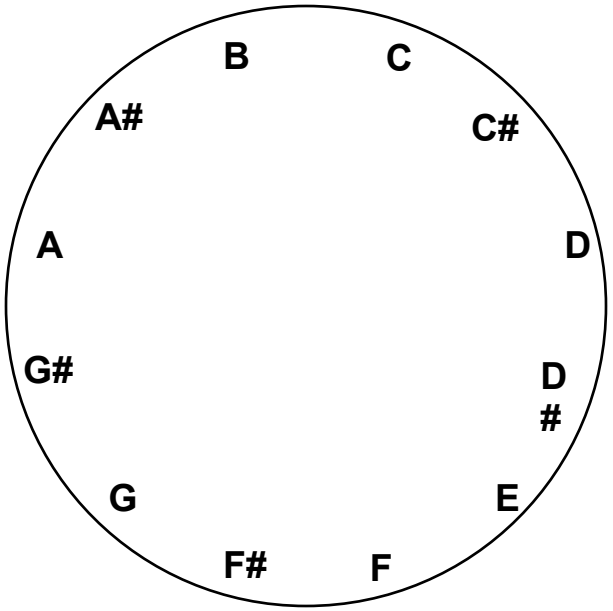
Cognitive dimensions of musical pitch

Pitch height dimension (as linear continuum)

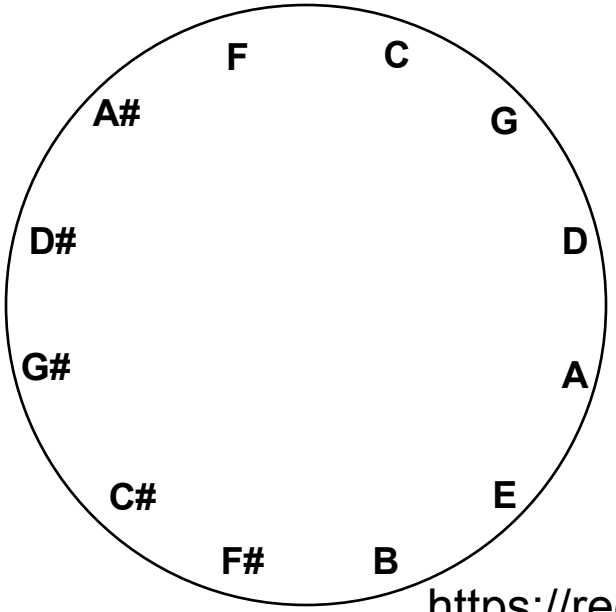
Pitch height dimension (as discrete linearly-organised categories)

C	2
B	2
A#	2
A	2
G#	2
G	2
F#	2
F	2
E	2
D#	2
D	2
C#	2
C	1
B	1
A#	1
A	1
G#	1
G	1

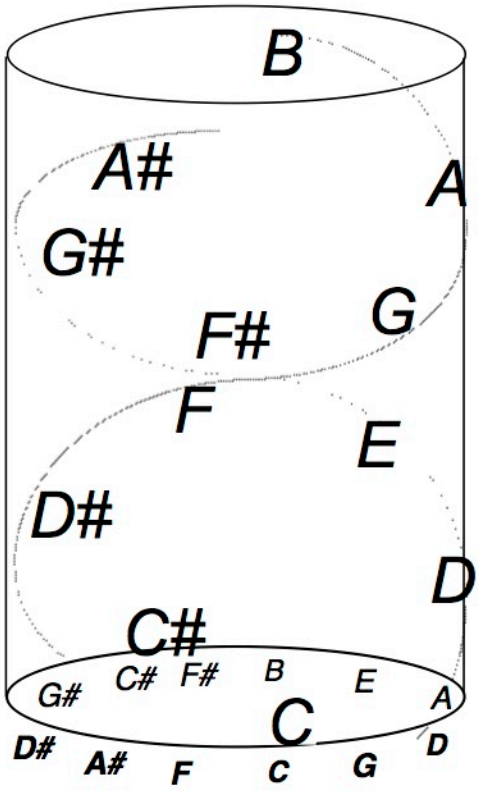
Chroma circle

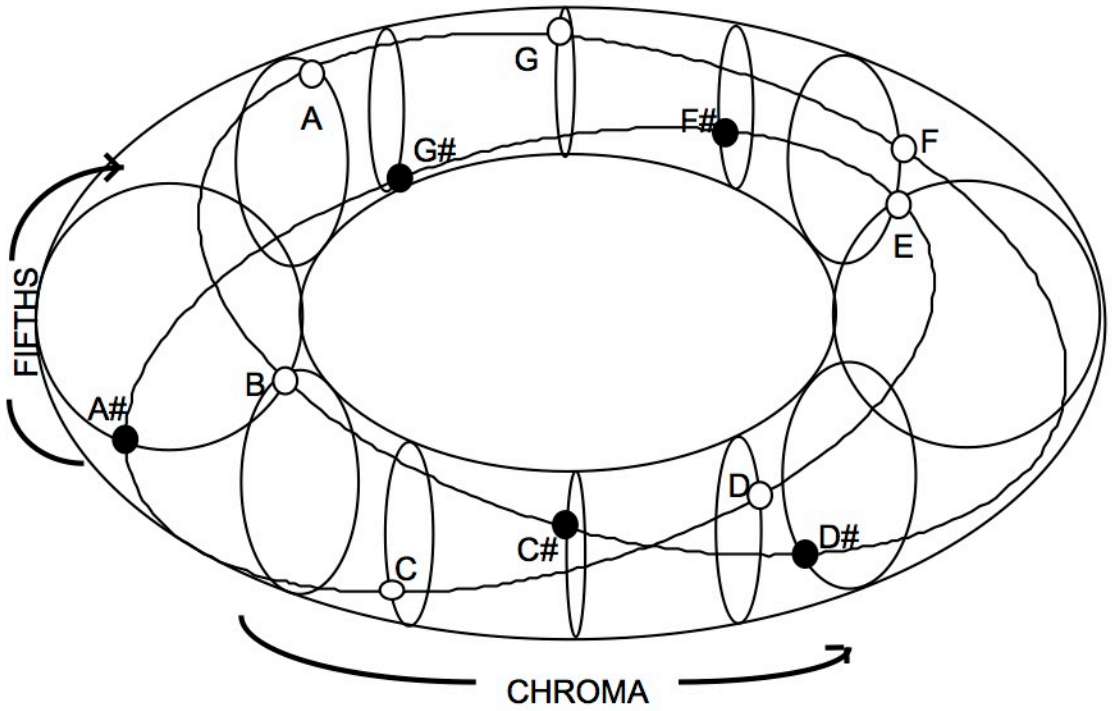


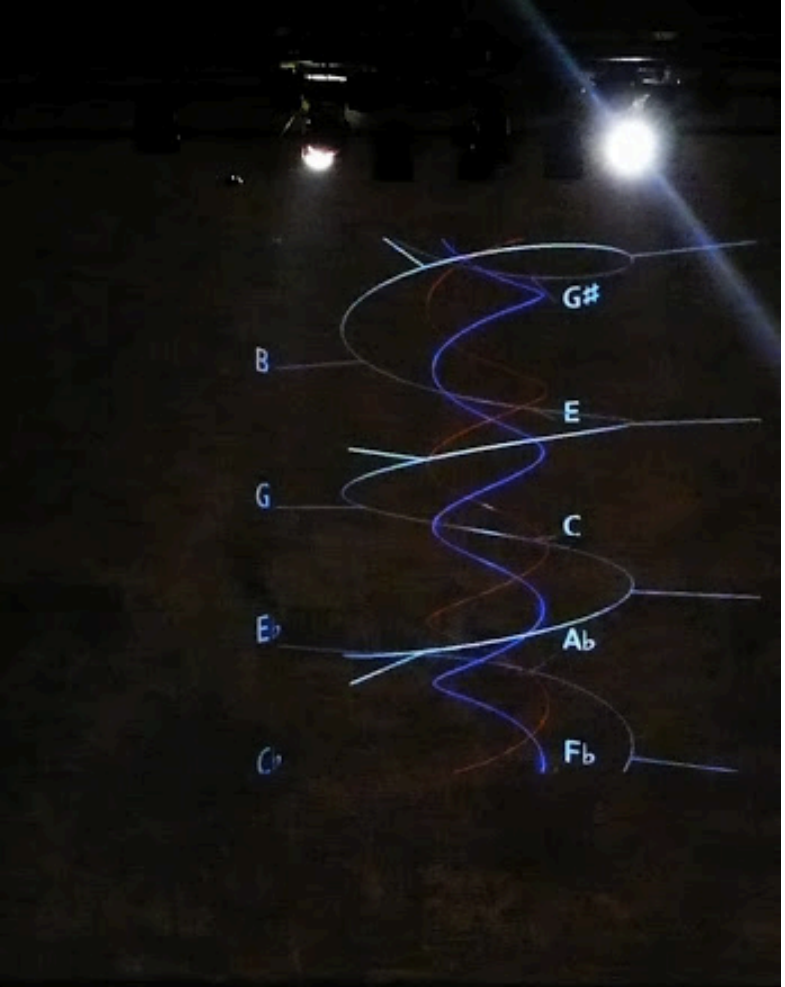
Circle of fifths



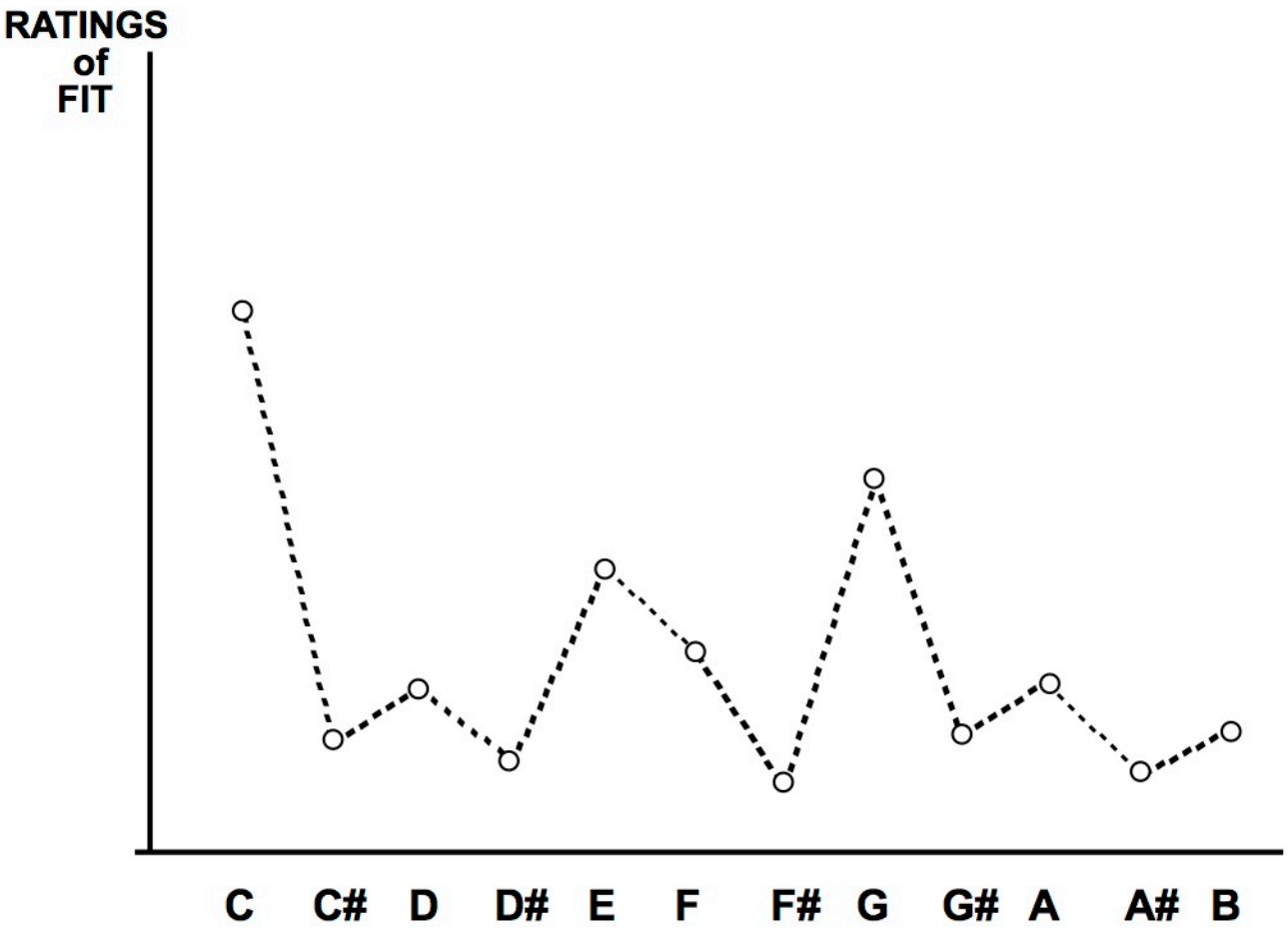
https://recursivearts.com/virtual-piano/


B
A#
A
G#
G
F#
F
E
D#
D
C#
G#
C#
F#
B
E
A
C
D#
A#
F
C
G
D

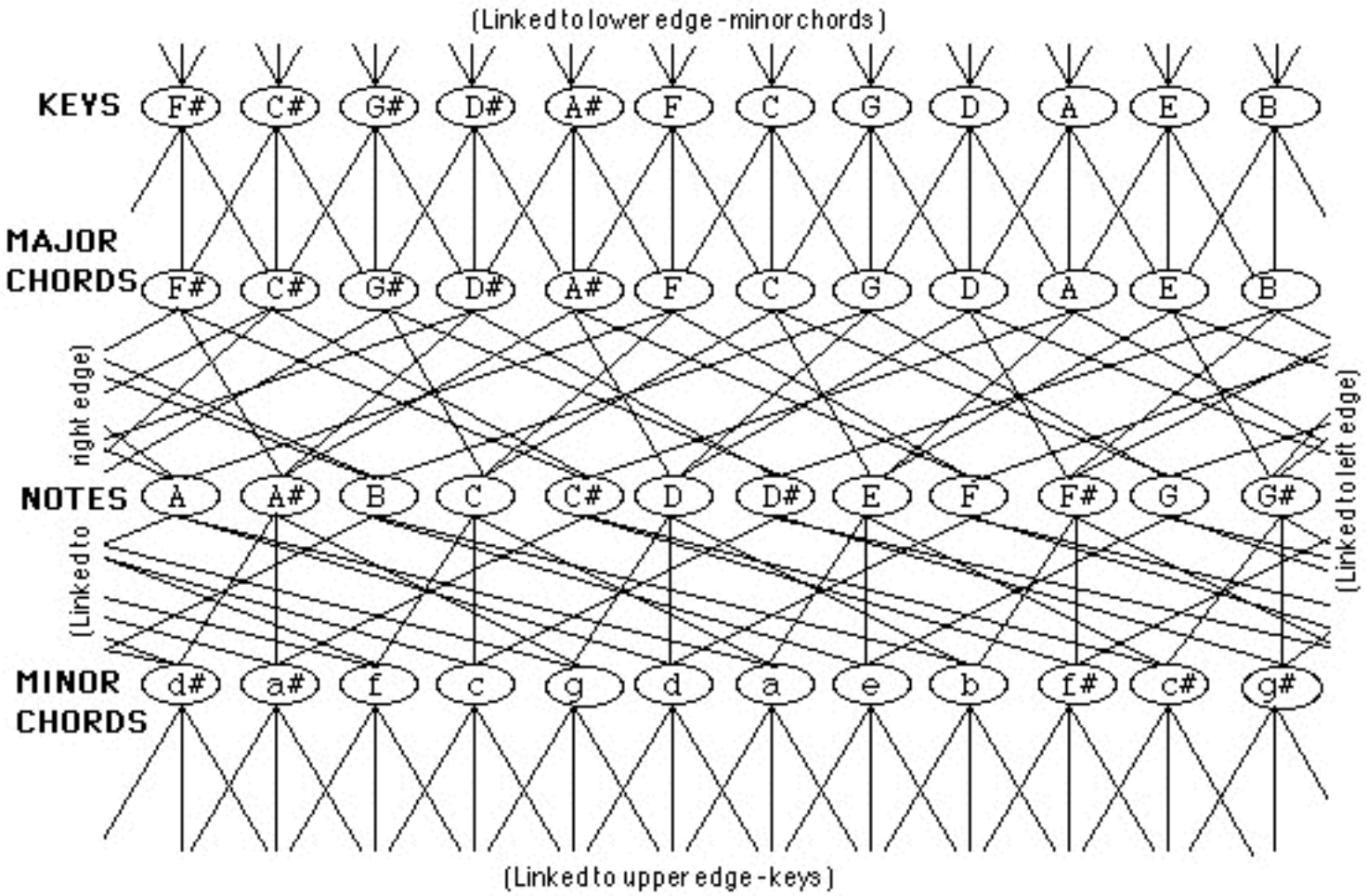

G
A
G#
F#
F
E
FIFTHS
A#
B
D
C#
D#
C
CHROMA



Elaine Chew



after Krumhansl, 1990



Units and links in Bharucha's MUSACT system

Cognitive approaches to pitch
Intervallic rivalry theory

- Long term vs. short term memory
- Dynamic vs. static attributes of tonal structure

- Intervallic rivalry model
  - **Centres on processes of key discovery,**
- Cognitive-structuralist account
  - **Centres on processes of reinforcement of tonal function.**

- Both necessary for a listener to follow tonal music in real time.

- "psychology of ear training”
  - not
- "psychology of music”

Cook 1994

Summary

- It's likely that all these processes –
  - of **auditory scene analysis**, of the **abstraction and schematicisation in long-term memory of regularities of musical pitch organisation**, (as well as of the **abstraction of the 'virtual roots' and relative stabilities of chords**)
- play significant and determinant roles in our experience of pitch organization in music.

Cross 1997

What would a theory of our perception of musical pieces take into account?

- Several theories have been proposed.
- Don't have a comprehensive theory that deals with all the different processes that seem to be going on when we experience a piece of music.

Perception

Production

Lab

Beyond

- Pitch
- Rhythm
- Time
- Phrasing
- Movement
- Language
- Emotion
- Development
- Performance (improvisation)
- Musicians' health
- Brain
- Body
- Evolution
- Health & wellbeing
- Daily life

Solo

Social
- Duo
- More

- Entrainment
- Two-person neuroscience

Language and linguistics

Computer Science & AI

Anthropology

Neuroscience

Psychology

Child development Education

Medicine

Music Therapy

- Pitch
- Rhythm
- Time
- Phrasing
- Movement
- Language
- Emotion
- Development
- Performance (improvisation)
- Musicians' health
- Brain
- Body
- Evolution
- Health & wellbeing
- Daily life

Musicology

Ethnomusicology

Performance

Dance / Dance psychology

Self report

Questionnaire

Interview

Focus group

Experience Sampling

Neuro

Physiological

Music analysis

- Pitch
- Rhythm
- Time
- Phrasing
- Movement
- Language
- Emotion
- Development
- Performance (improvisation)
- Musicians' health
- Brain
- Body
- Evolution
- Health & wellbeing
- Daily life

Observation

Video

Audio

Task based

Comparison groups

Modelling

Some reading

Bregman, A. L.	1994	Auditory Scene Analysis . Ch 2 in McAdams, S. & Bigand, E. (Eds), Thinking in sound. Oxford: OUP.
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Drake, C., & Parncutt, R.	2001	"Perception and Cognition: Rhythm" in the revised *New Grove Dictionary of Music,* London, Macmillan
Jones, M.R.	2016	"Music time" in *Oxford Handbook of Music Psychology,* ed. Hallam, Cross & Thaut, OUP (2nd edn)
Krumhansl, C. L.	1990	Cognitive foundations of musical pitch. Oxford: OUP.
London, J.	2001	"Rhythm" in the revised *New Grove Dictionary of Music,* London, Macmillan.
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Pöppel, E., & Wittmann, M.	1999	"Time in the Mind" in the *MIT Encyclopedia of the Cognitive Sciences,* MIT Press.