Measuring Roughness: considerations for the microtonalist

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Contexts

- exploration of xenharmonic scales and the holistic inclusion of factors such as interface and timbre as factors
- ...and also assess historical uses of tunings and perceptions of dissonance - as these can differ from our own
- The use of the scale leads to the evolution of a music theory - implicitly connected with this is some concept of consonance/ dissonance

Roughness

- Roughness one of the auditory attributes along with Pitch, Timbre and Loudness.
- as distinct from dissonance - culturally loaded and context dependent
- dissonance = 'sensory dissonance'
- first research without cultural bias: Helmholtz 1885
- little research carried out in the area until the 1960's (with the exception of von Békésy's work in the 1930-40's)
- von Békésy, (1960); Terhardt, (1974); Plomp & Levelt, (1965); Kameoka & Kuriyagawa, (1969); Hutchinson & Knopoff, (1978); Sethares, (1998)

Consonance & Dissonance

- That certain conditions cause the ear to be 'thrown into turmoil' has been observed throughout the ages.
- psychoacoustics research explains these physiological and perceptual phenomena.
- tones which lie closely together in frequency exhibit a phenomenon known as beating as they cycle in and out of phase with one another rapidly.
- this swift beating (fluttering) is perceived as roughness and persists until the tones are separated by a distance known as the critical band.
- when a number of tones and or their partials lie within the same critical band - roughness is experienced.

Critical Bands

- Fletcher's 'Auditory Patterns', (1940) - the graphics highlight areas of excitation on the basilar membrane

- the existence of CBs was confirmed by the phenomenon of masking: a noise signal concealed a sine wave from the subject. However, when the the sine wave was swept up or down in pitch, it it would reappear - confirming the existence of place-specific areas of sensitivity.

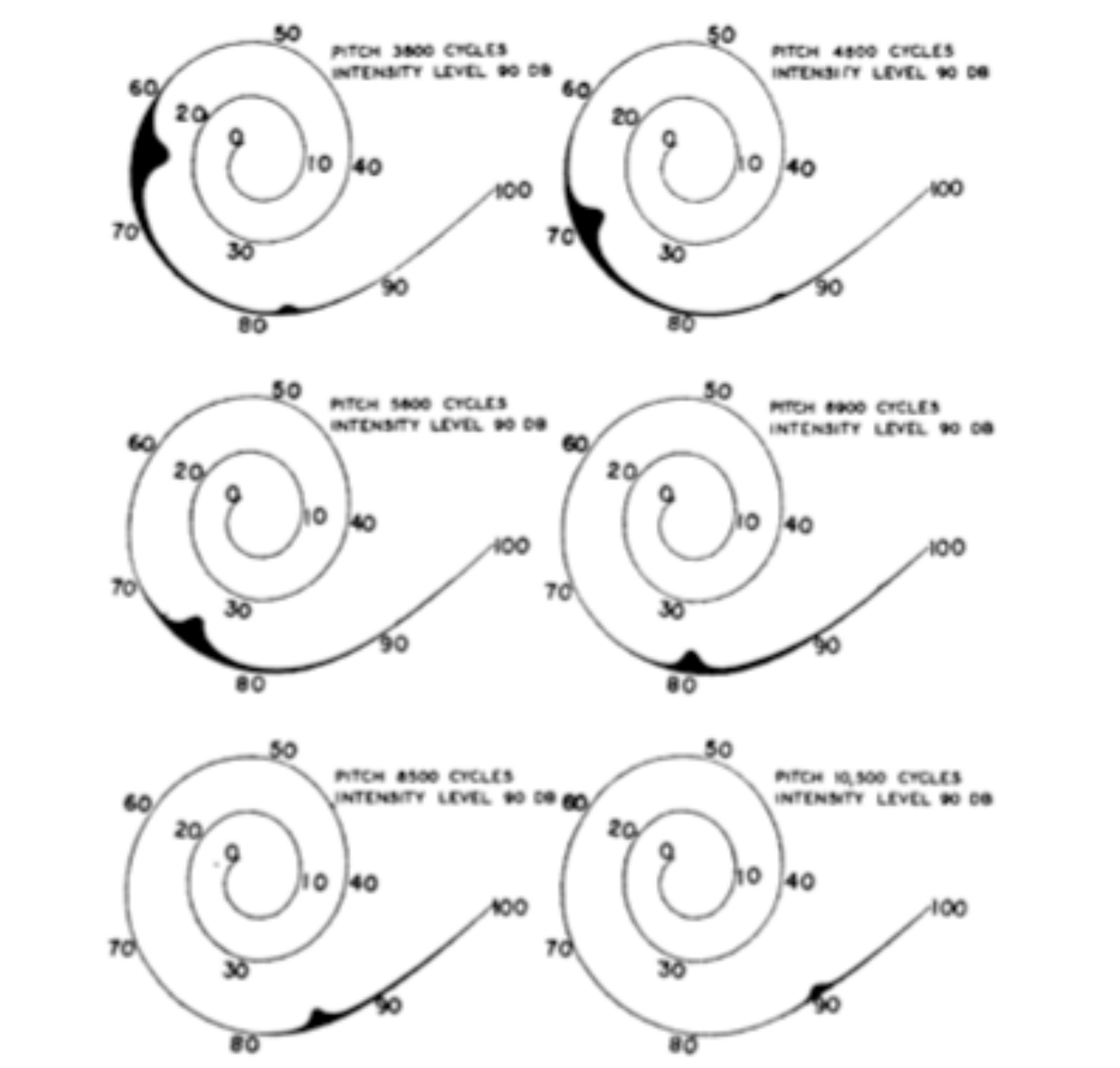


FIG. 11. Auditory patterns at 90 db for various frequencies.

Fletcher 'Auditory Patterns' (1940)

Critical Bands

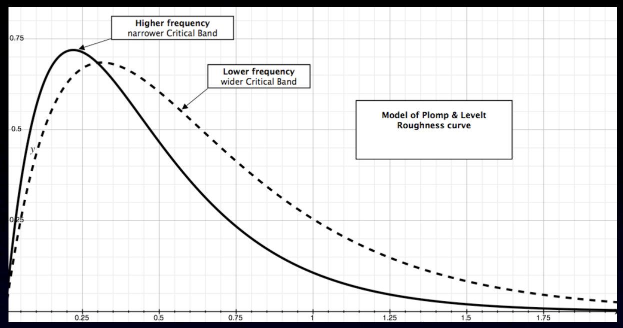
- The width of the CBs was later mapped by Zwicker, 'Subdivision of the Audible Frequency Range (Frequenzgruppen)', (1961)
- and presented as a table

TABLE I.

Number	Center frequencies Hz	Cut-off frequencies Hz	Bandwidth Hz
		20	
1	50	100	80
2	150	200	100
3	250	300	100
4	350	400	100
5	450	510	110
6	570	630	120
7	700	770	140
8	840	920	150
9	1000	1080	160
10	1170	1270	190
11	1370	1480	210
12	1600	1720	240
13	1850	2000	280
14	2150	2320	320
15	2500	2700	380
16	2900	3150	450
17	3400	3700	550
18	4000	4400	700
19	4800	5300	900
20	5800	6400	1100
21	7000	7700	1300
22	8500	9500	1800
23	10 500	12 000	2500
24	13 500	15 500	3500

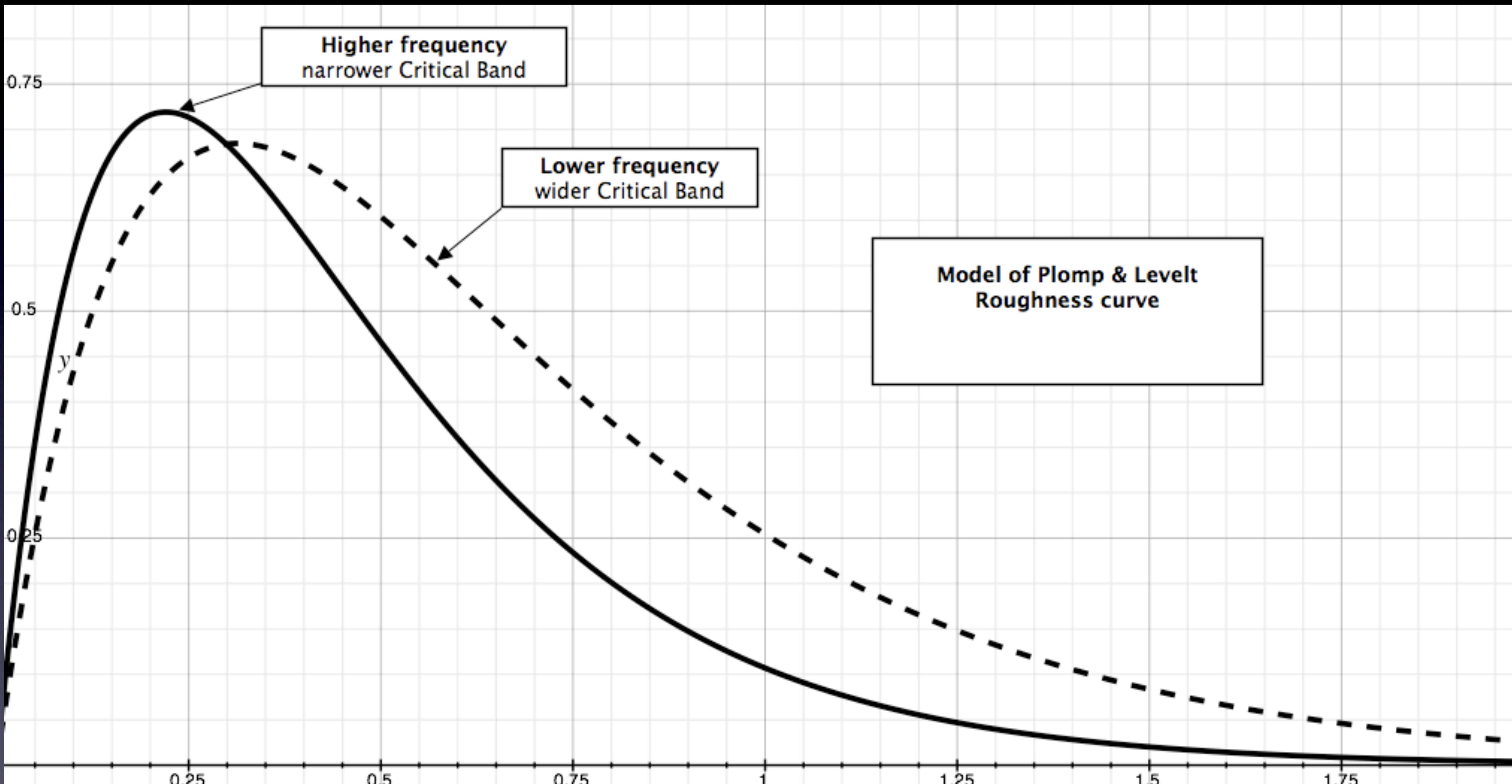
*Zwicker's 'hypothetical analysis filters' (1961)

Plomp & Levelt



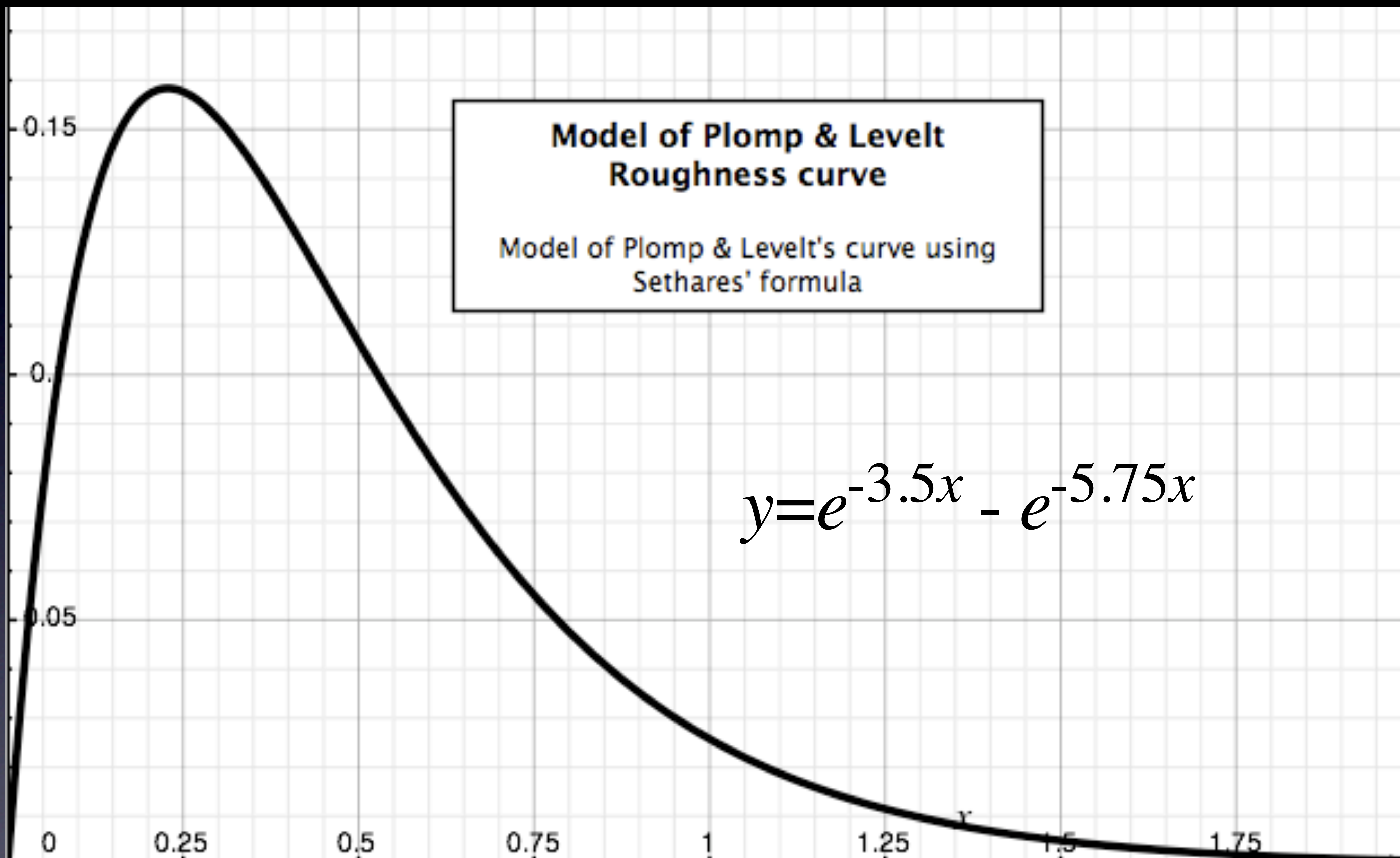
- First to tie concept of roughness perception to the parameters of the Critical Band*
- found that maximum roughness point occurs at 1/4 width of the CB
- and that the curve is wider for lower frequencies

*Zwicker's 'hypothetical analysis filters' (1961) - first proposed by Fletcher 'Auditory Patterns' (1940)



Higher frequency
narrower Critical Band
Lower frequency
wider Critical Band
Model of Plomp & Levelt
Roughness curve
0.75
0.5
0.25
y
0.25
0.5
0.75
1
1.25
1.5
1.75

Sethares



$$y=e^{-3.5x} - e^{-5.75x}$$

Terhardt

- attributes the sensation of roughness directly to temporal fluctuations in amplitude when they appear within the 'spectral regions' known as critical bands (CBs).
- the roughness created across all of the CBs is summed to give an overall roughness effect
- confirming the assumption that, for a pair of timbres, adjacent partials of each timbre that lie within the same CB will contribute to the overall sensation of roughness.
- Terhardt mentions phase but does not present any process for dealing with it

Parncutt

- Terhardt's ideas (tonalness, virtual pitch) were extended by Parncutt.
- applied them to common practice music & 12 tet composition
- implemented an extended version of Hutchinson & Knopoff's roughness algorithm

Vassilakis

- pan-musical interdisciplinary dissertation (2005) inclusive of non-Western music
- clarifies the confusion surrounding amplitude fluctuation and amplitude modulation depth
- highlights importance of roughness as an integral sonic attribute of many types of music
- revises models estimating to roughness of complex tones with a compensating curve

Implementations in Pure Data

Bohlen Pierce

- non-octave scale with 13 steps
- repeats every 12th
- Just Intonation and Equal Tempered versions
- None of the BP scales sit well on the physical key arrangement of the 12-TET keyboard
- so following from Elaine Walker (and from Heinz Bohlen) , a standard MIDI keyboard was repurposed into a B-P instrument

Bohlen Pierce Just Intonation

- BP Just Intonation (JI) chromatic

  1/1, 27/25, 25/21, 9/7, 7/5, 75/49, 5/3, 9/5, 49/25, 15/7, 7/3, 63/25, 25/9, 3/1

- BP JI diatonic: ‘Lambda Mode’

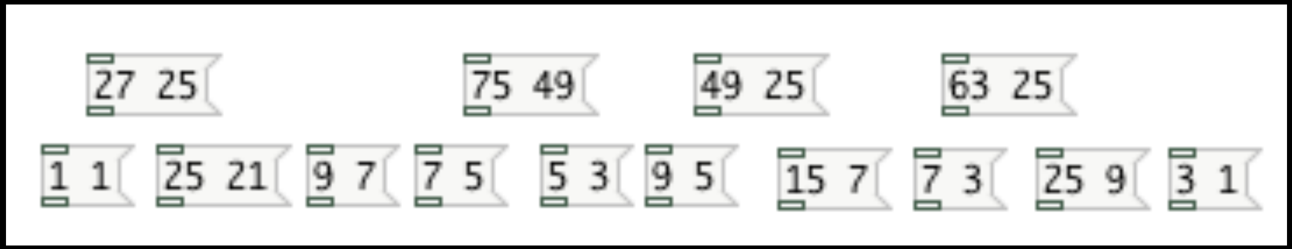
  1/1, 25/21, 9/7, 7/5, 5/3, 9/5, 15/7, 7/3, 25/9, 3/1

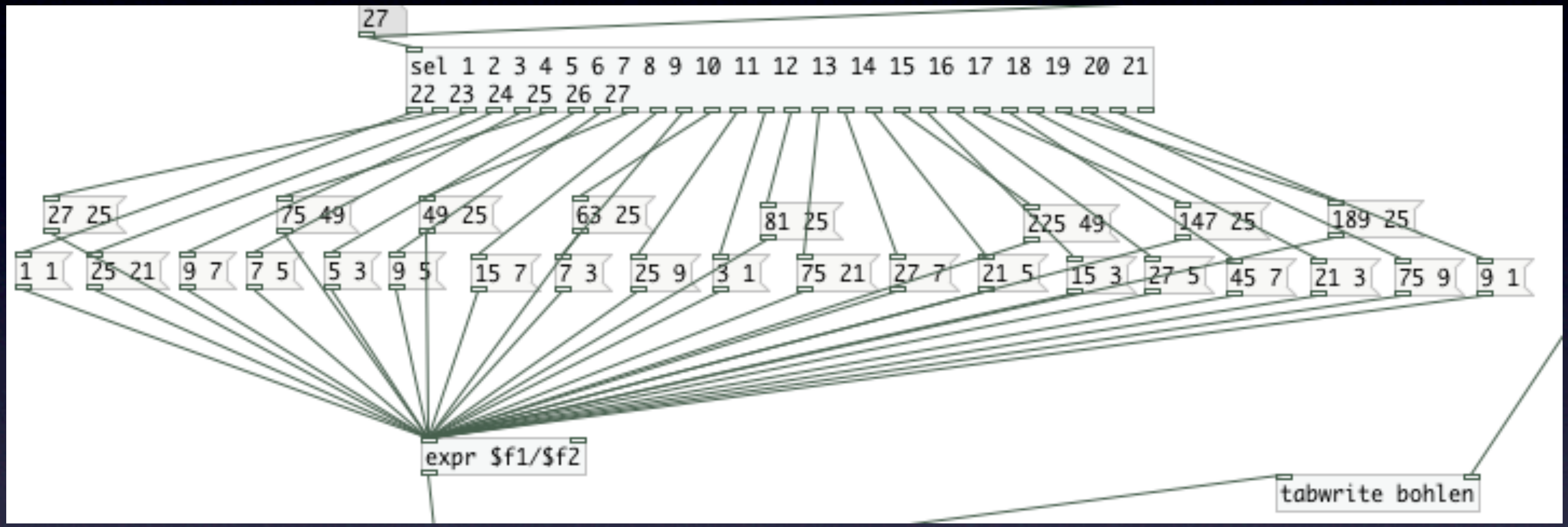
C	D	E	F	G	H	J	A	B	C’
1/1	25/21	9/7	7/5	5/3	9/5	15/7	7/3	25/9	3/1

'The Bohland' interface

- The keyboard provides a 'front-end' for an additive synthesis instrument implemented in Pure Data. The partials have high resolution frequency and amplitude controls, and there are individual envelopes on each partial.
- Diatonic BP notes mapped to white keys, and the ratios corresponding to the chromatic notes are mapped to the reconfigured black keys.
- Only parts of the MIDI protocol are used (e.g., velocity). The frequency values assigned to the keys are not used; instead each unique MIDI note ID is re-assigned to trigger scale maps created within the pd patch itself.
- The synthesizer allows the user to select either ET or JI BP scales

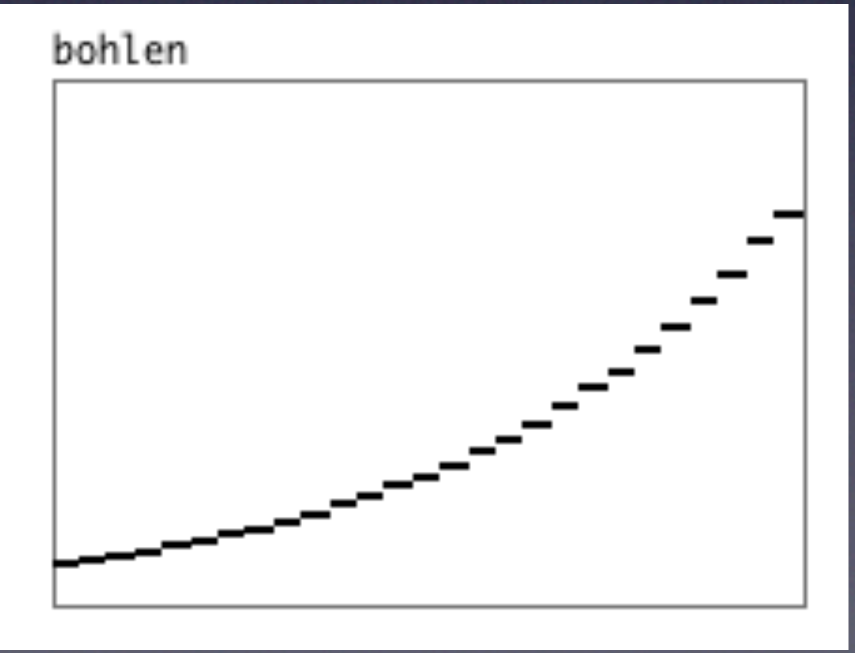
BP JI chromatic scale mapped out as a set of message boxes in pd





These are then sent sequentially through an expression for the calculation of the ratios...

... and mapped out on an array to provide scale ratios to be applied to a base frequency



Timbres that complement B-P

- B-P practitioners have traditionally chosen timbres consisting of odd integer multiples of the fundamental.
- Preliminary tests with triangle and square waves confirmed the suitability of these types
- Sethares presents a useful way of constructing a spectrum for a given scale
- 'Symbolic Computation of Spectra' is a technique for selecting spectral components with the goal of maximising the number of co-incident partials.
- This is accomplished by ensuring that the ratios between the partials are equal to some interval in the scale.

	1/1	27/25	25/21	9/7	7/5	75/49	5/3	9/5	49/25	15/7	7/3	63/25	25/9	3/1
⊕	**(0,0,0,0)**	**(1,0,0,0)**	**(1,1,0,0)**	**(2,1,0,0)**	**(2,1,1,0)**	**(2,1,1,1)**	**(2,1,2,1)**	**(3,1,2,1)**	**(3,1,3,1)**	**(3,1,3,2)**	**(3,1,4,2)**	**(4,1,4,2)**	**(4,2,4,2)**	**(5,2,4,2)**
(0,0,0,0)	(0,0,0,0)	(1,0,0,0)	(1,1,0,0)	(2,1, 0,0)	(2,1,1,0)	(2,1,1,1)	(2,1,2,1)	(3,1,2,1)	(3,1,3,1)	(3,1,3,2)	(3,1,4,2)	(4,1,4,2)	(4,2,4,2)	(5,2,4,2)
(1,0,0,0)	(1,0,0,0)	*	(2,1, 0,0)	*	*	*	(3,1,2,1)	*	*	*	(4,1,4,2)	*	(5,2,4,2)	(1,0,0,0)
(1,1,0,0)	(1,1,0,0)	(2,1,0,0)	*	*	*	*	*	*	*	*	(4,2,4,2)	(5,2,4,2)	*	(1,1,0,0)
(2,1,0,0)	(2,1,0,0)	*	*	*	*	*	*	*	*	*	(5,2,4,2)	(1,0,0,0)	(1,1,0,0)	(2,1,0,0)
(2,1,1,0)	(2,1,1,0)	*	*	*	*	*	*	*	*	(5,2,4,2)	*	*	*	(2,1,1,0)
(2,1,1,1)	(2,1,1,1)	*	*	*	*	*	*	*	(5,2,4,2)	*	*	*	*	(2,1,1,1)
(2,1,2,1)	(2,1,2,1)	(3,1,2,1)	*	*	*	*	(4,2,4,2)	(5,2,4,2)	*	*	*	*	*	(2,1,2,1)
(3,1,2,1)	(3,1,2,1)	*	*	*	*	*	(5,2,4,2)	(1,0,0,0)	*	*	*	*	(2,1,2,1)	(3,1,2,1)
(3,1,3,1)	(3,1,3,1)	*	*	*	*	(5,2,4,2)	*	*	*	*	*	*	*	(3,1,3,1)
(3,1,3,2)	(3,1,3,2)	*	*	*	(5,2,4,2)	*	*	*	*	*	*	*	*	(3,1,3,2)
(3,1,4,2)	(3,1,4,2)	(4,1,4,2)	(4,2,4,2)	(5,2,4,2)	*	*	*	*	*	*	*	*	*	(3,1,4,2)
(4,1,4,2)	(4,1,4,2)	*	(5,2,4,2)	(1,0,0,0)	*	*	*	*	*	*	*	*	(3,1,4,2)	(4,1,4,2)
(4,2,4,2)	(4,2,4,2)	(5,2,4,2)	*	(1,1,0,0)	*	*	*	(2,1,2,1)	*	*	*	(3,1,4,2)	*	(4,2,4,2)
(5,2,4,2)	(5,2,4,2)	(1,0,0,0)	(1,1,0,0)	(2,1, 0,0)	(2,1,1,0)	(2,1,1,1)	(2,1,2,1)	(3,1,2,1)	(3,1,3,1)	(3,1,3,2)	(3,1,4,2)	(4,1,4,2)	(4,2,4,2)	(5,2,4,2)

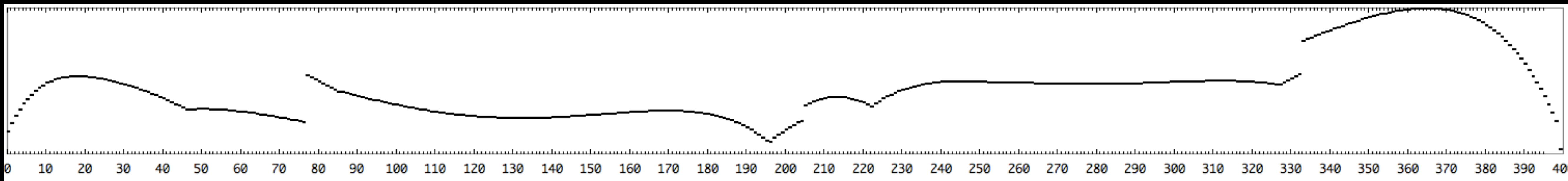
- Table shows the relationship between the scale intervals: * represent non-scale intervals - disallowed
- Intervals that make up B-P JI scale are: a=27/25, b=625/527, c=49/45, d=375/343

i	1	2	3	4	5	6	7	k
t(i)	(0,0,0,0)	(5,2,4,2)	(9,4,8,4)	(12,5,8,4)	(13,5,10,5)	(13,5,12,6)	(14,5,12,6)	
s(i)	(0,0,0,0)	(0,0,0,0)	(4,2,4,2)	(2,1,0,0)	(3,1,2,1)	(3,1,4,2)	(4.1.4.2)	
r (i,k)		(5,2,4,2)	(4,2,4,2)	*	*	*	(1,0,0,0)	**1**
			(4,2,4,2)	(2,1,0,0)	*	*	*	**2**
				(2,1,0,0)	(3,1,2,1)	(4,1,4,2)	*	**3**
					(3,1,2,1)	(3,1,4,2)	*	**4**
						(3,1,4,2)	(4.1.4.2)	**5**
							(4.1.4.2)	**6**

- Spectrum t(i) constructed by consulting O-plus table and selecting likely candidates. Then partials are tested against each other: f(i)/f(j) = scale step. In this case, not all of the ratios between partials are scale steps, so this timbre is only partly related to the B-P scale

Roughness curves

- in contrast to the JI advocates, tuning creators who manipulate timbral components for the purposes of achieving coherence of partials with scales that would not work with acoustic timbres occupy a space of their own in contemporary tuning studies.
- utilising the flexibility granted by digital synthesis and control systems, researchers are able to create scales that would be bereft of consonance if used with timbres containing ‘partial placements’ usually associated with traditional instruments.
- The reverse process also holds true - a unique scale can be derived from a given timbre - the following slides present a worked example.

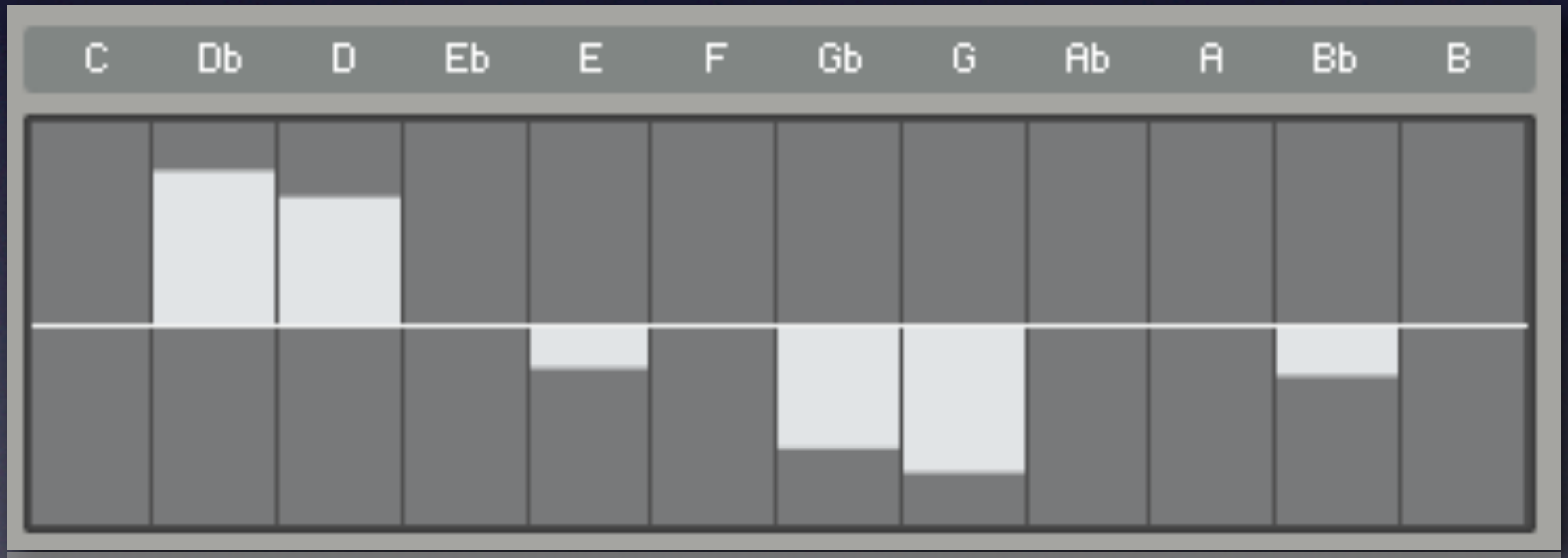


- dissonance curve of spectrum of waterphone sample drawn using Moore and Glasberg's formula for the calculation of CB
- the pd patch models the way the ear perceives dissonance by reacting each partial together and testing for roughness. The amplitude of the partials is taken into account, as is register, by including a critical band model.
- the result is a curve which clearly shows the 'dissonance minima'
- it is at these points that the scale steps are fixed
- In this case the next most consonant interval, after unison (8ve), is a type of tritone - this timbre supports the tritone as a consonant interval

Dissonance curve

- To port these minima over so that they form a meaningful scale it is necessary to get the values out of the table and into a scale implementation device
- this time Kontakt was used: both to host the samples and to implement the scales. It has the disadvantage of being 8ve based.
- the values from 0-400 are easily readable from the curve x-axis
- these are *3 to give 1200 - so that it now fits neatly across a 12 TET span
- the values end up as follows: a 7-step scale

Curve values for minima points	*3 (1200 cents)	Assigned note - Kontakt
0	0	C (base note)
46	138	Db
77	231	D
130	390	E
196	570	Gb
222	666	G
329	987	Bb



Notes Eb, F, Ab, A & B not used in this case

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- Moore & Glasberg's CB equation. Fcb = critical bandwidth, Fm = mean frequency

$$f_{cb} = 0.108 f_m + 24.7$$

Moore, B.C.J., Glasberg, B.R.: A revision of Zwicker's loudness model. Acustica 82, (1996)