Similarity Measurements in Chopin Mazurka Performances

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Queen Mary, University of London

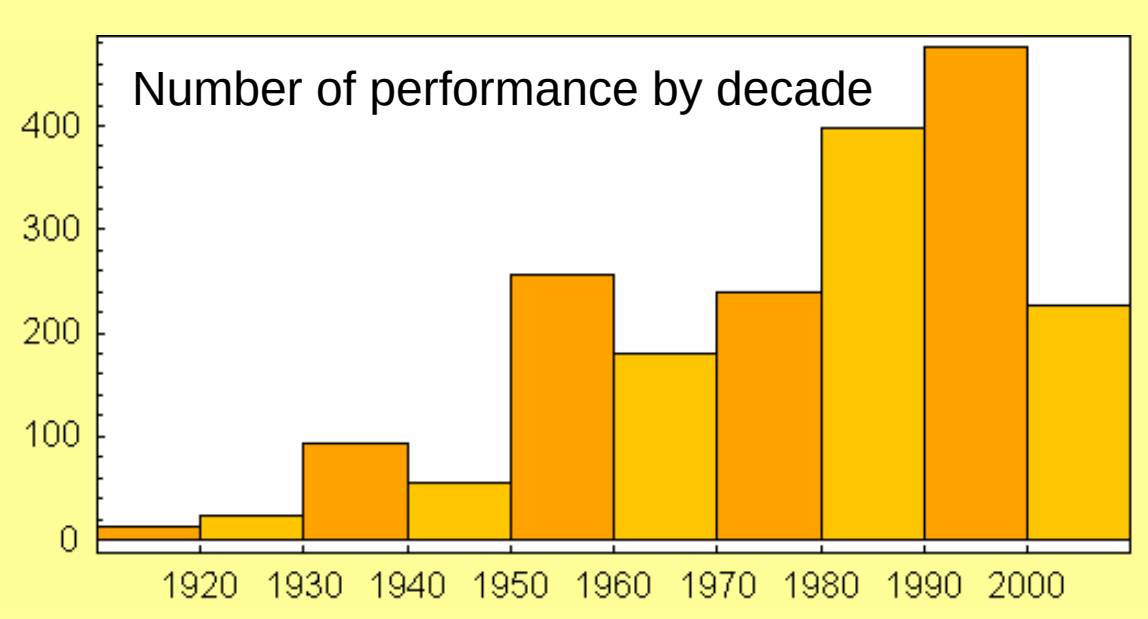
Mazurka Project

- **2,210 recordings of 49 mazurkas**
  = 45 performances/mazurka on average
  ***least*: 31 performances of 41/3**
  ***most*: 64 performances of 63/3**

Performers of mazurka 63/3:

Afanassiev (2001)	Friedman (1930)	Pachmann (1927)
Anderszewski (2003)	Gierżod (1998)	Paderewski (1930)
Ashkenazy (1981)	Gornostaeva (1994)	Perlemuter (1992)
Biret (1990)	Harasiewicz (1955)	Pobłocka (1999)
Blet (2003)	Hatto (1988)	Rabcewiczowa (1932)
Block (1995)	Horowitz (1949)	Rachmaninoff (1923)
Blumental (1952)	Indjic (1988)	Rangell (2001)
Boshniakovich (1969)	Kapell (1951)	Rosen (1989)
Brailowsky (1960)	Kissin (1993)	Rosenthal (1931)
Bunin (1987)	Kushner (1989)	Rubinstein (1939)
Chiu (1999)	Luisada (1991)	Rubinstein (1952)
Cohen (1997)	Lushtak (2004)	Rubinstein (1966)
Cortot (1951)	Magaloff (1978)	Schilhawsky (1960)
Czerny-Stefańska (1949)	Magin (1975)	Shebanova (2002)
Ezaki (2006)	Michałowski (1933)	Smith (1975)
Falvay (1989)	Milkina (1970)	Ts'ong (1984)
Ferenczy (1958)	Mohovich (1999)	Uninsky (1932)
Flière (1977)	Moravec (1969)	Uninsky (1971)
François (1956)	Neighaus (1950)	Wasowski (1980)
Friedman (1923)	Osinska (1989)	Zak (1937)

- **105 performers on 160 CDs, 98 hours of music**
- **Earliest is 1907 Pachmann performance of 50/2**



http://mazurka.org.uk/info/discography

Expressive Audio Features (Piano)

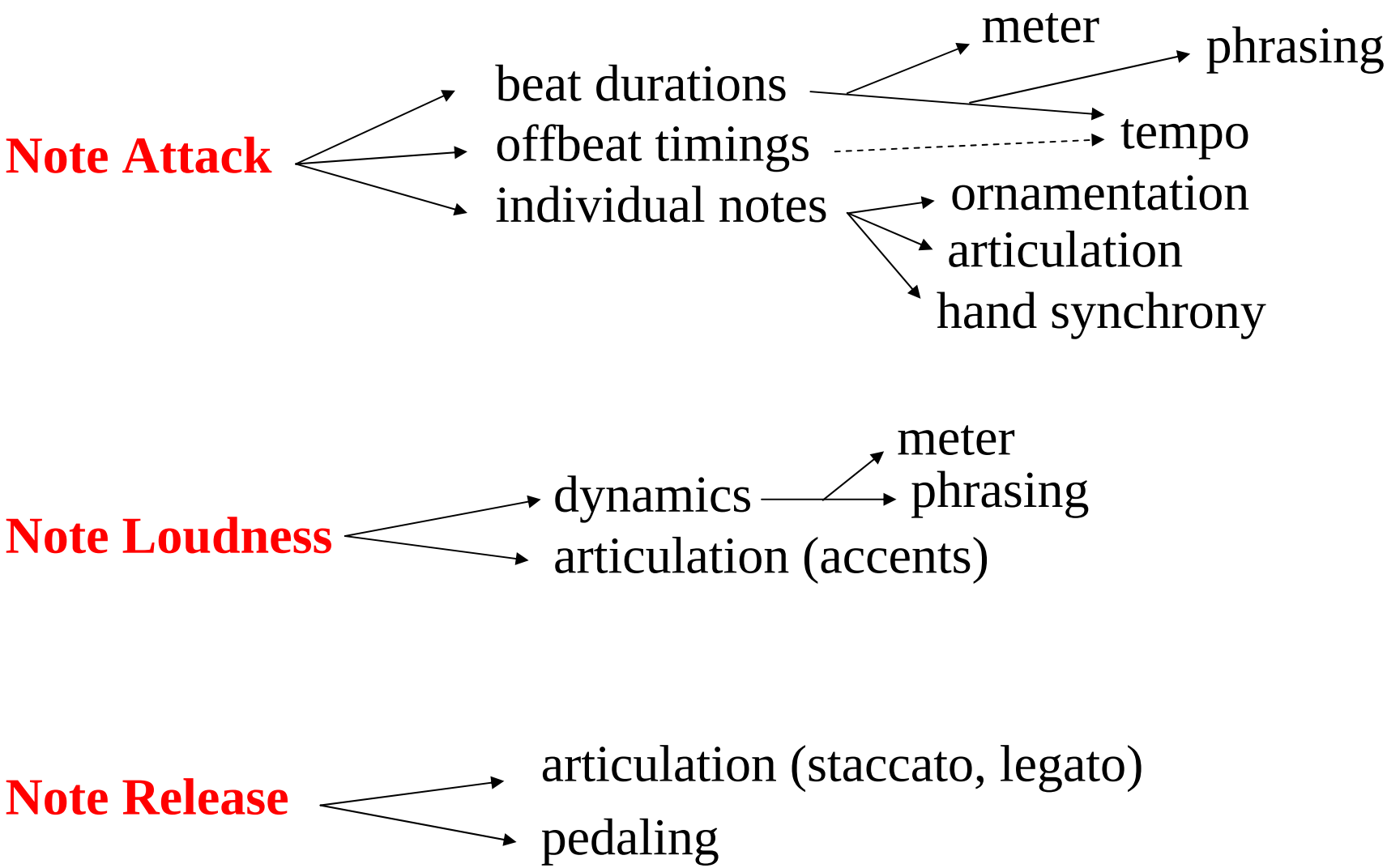
Note Attack

Note Loudness

Note Release

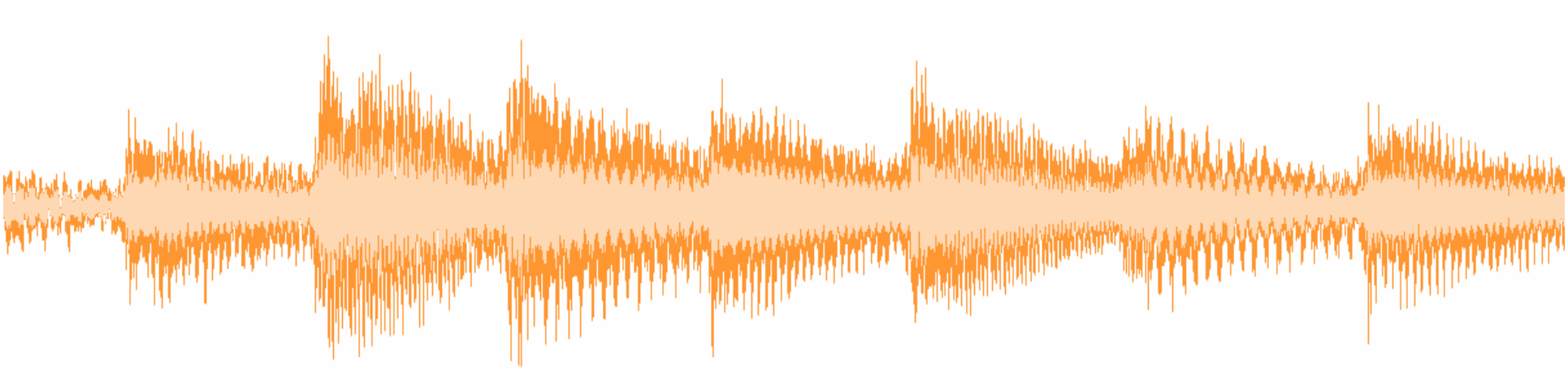
- Not much else a pianist can control
- String instruments have more control variables
- Voice has even more…

Expressive Performance Features



Data Extraction (1)

- Extracting beat times from audio files

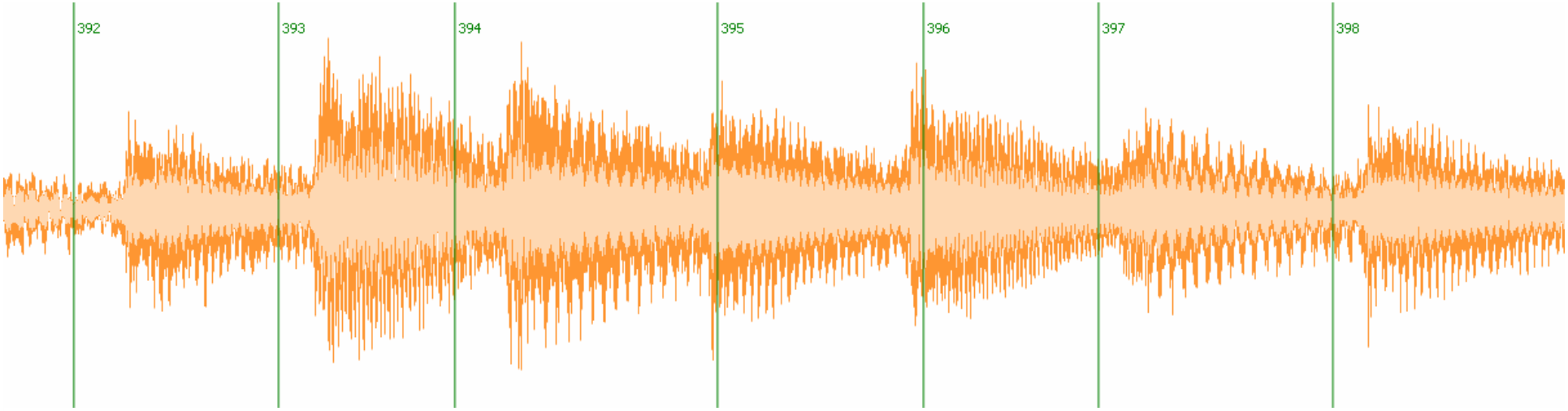


- Using Sonic Visualiser for data entry processing

http://www.sonicvisualiser.org

Data Extraction (2)

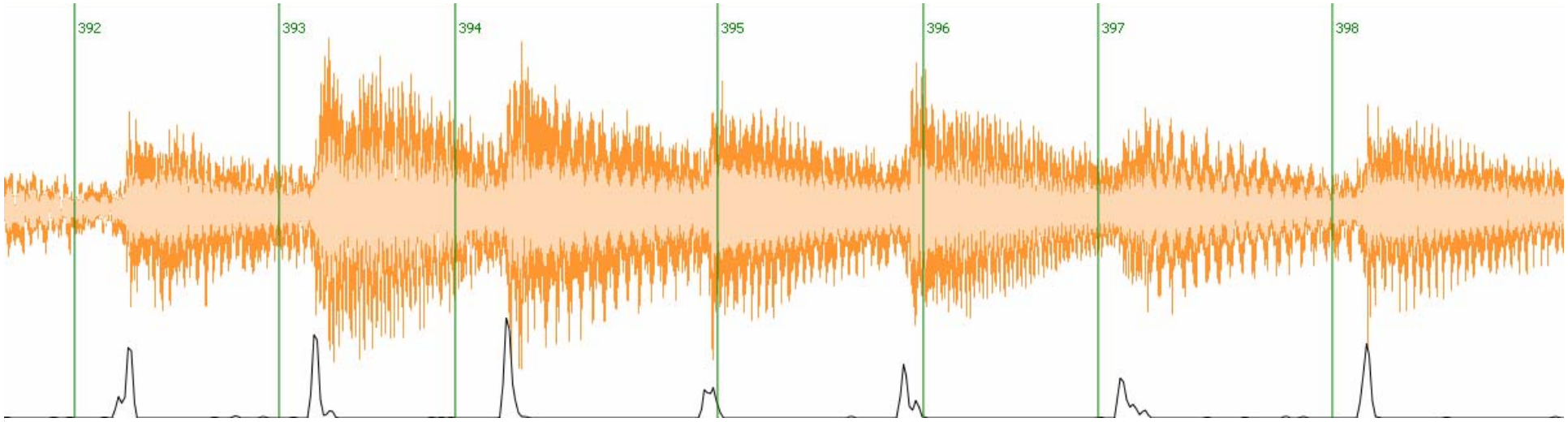
- Step 1: Listen to music and tap to beats (; key)



- Notice taps do not fall on the audio attacks:
  - 23.22 ms hardware granularity built into program
  - Human: ~30 ms SD for constant tempo; ~80 ms SD for mazurkas

Data Extraction (3)

- Step 2: Add onset detection function to the display

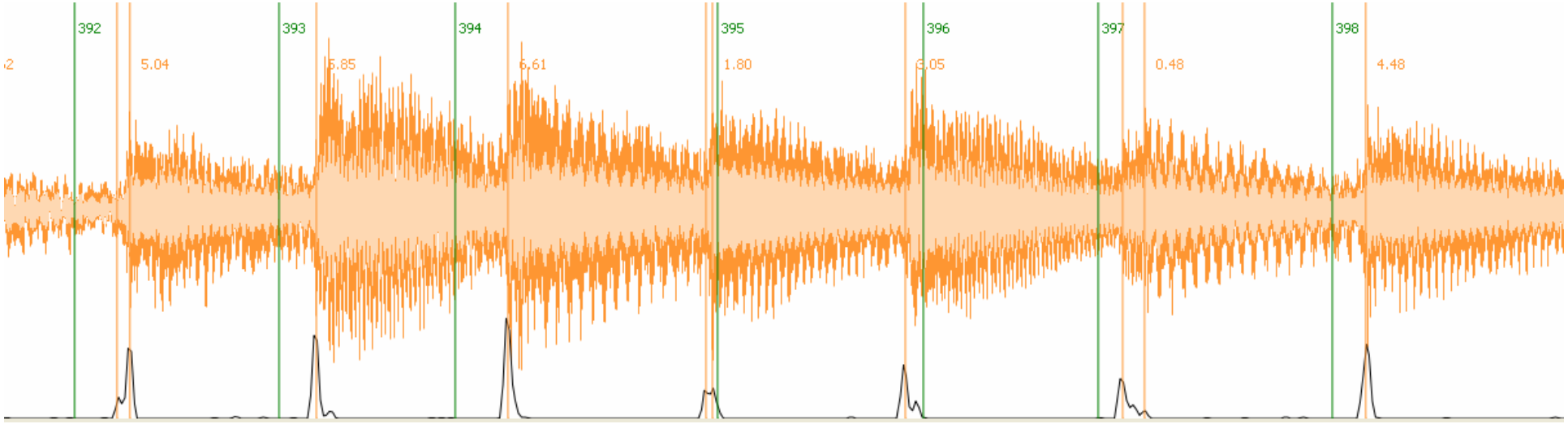


- *Mz*SpectralReflux plugin for Sonic Visualiser:

  http://sv.mazurka.org.uk/download (Linux & Windows)

Data Extraction (4)

- Step 3: Estimate onset times from function peaks



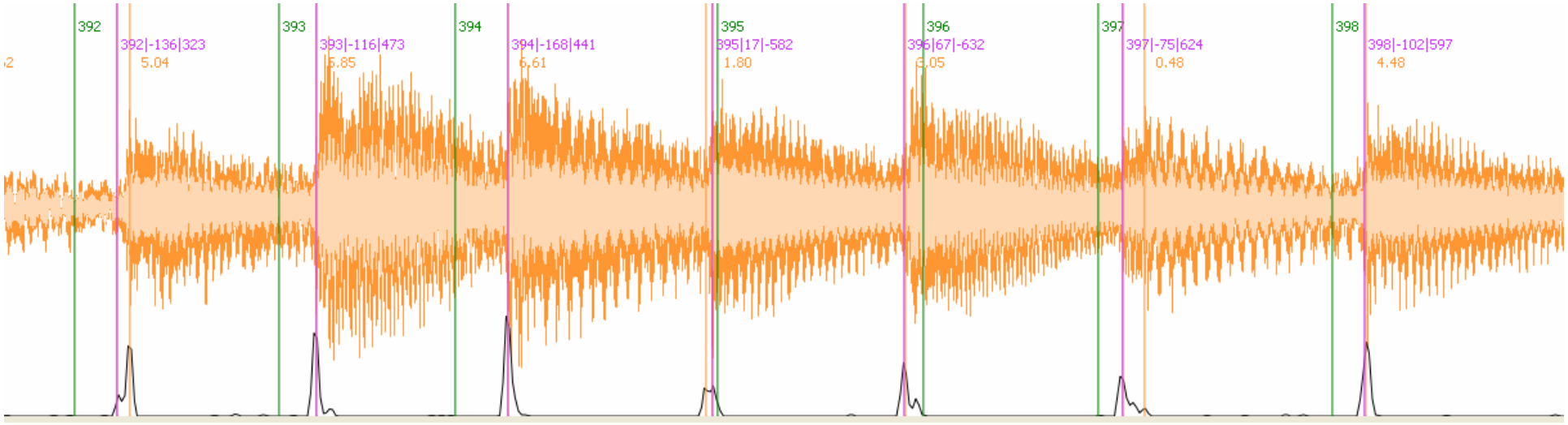
- Send taps (green) and onsets (orange) to external program:

  http://mazurka.org.uk/cgi-bin/snaptap

(no interlayer processing plugins for Sonic Visualiser yet…)

Data Extraction (5)

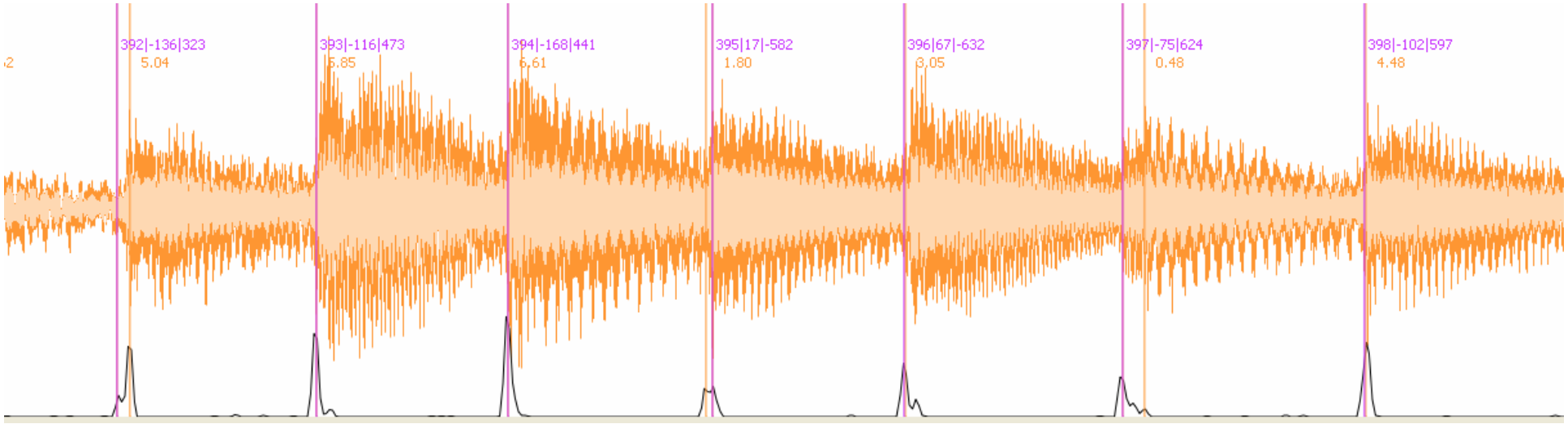
- Step 4: Load snaptap results into SV (purple):



- *Mz*SpectralReflux currently sentitive to noise (old recordings) so snaptap only works on clean recordings.

Data Extraction (6)

- Step 5: Correct errors

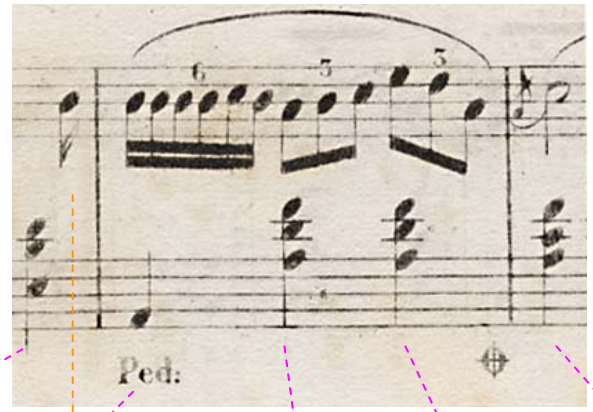


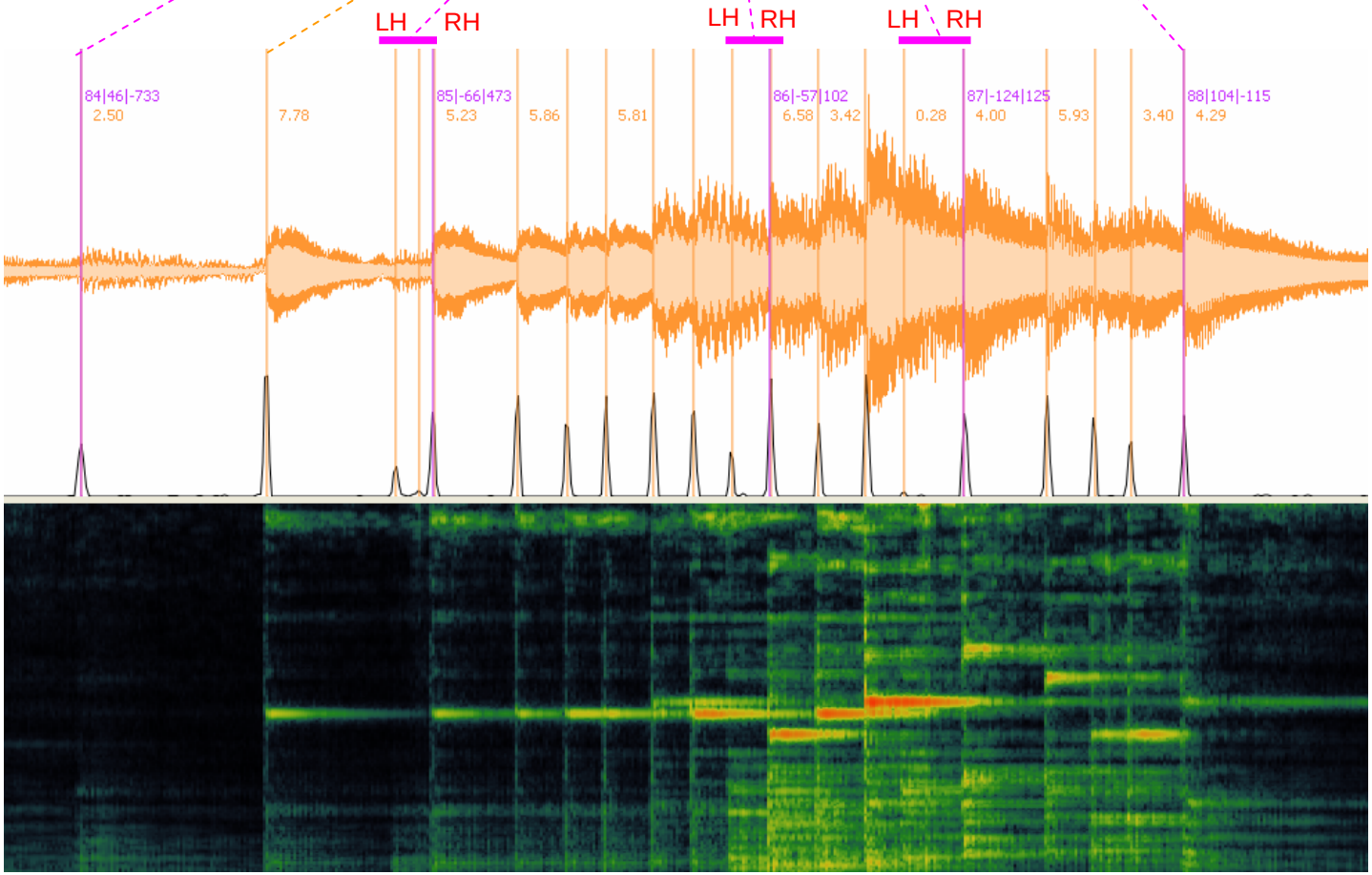
- Hardest part of data entry.
- Down to ~30 min/mazurka for clean recordings.
- 278 performances (of ~6 mazurkas) at this stage.

Well-Behaved

(Mohovich 1999)

- pickup longer than 16th
- LH before RH
- triplets played same speed as sextuplets
- first sextuplet note longest





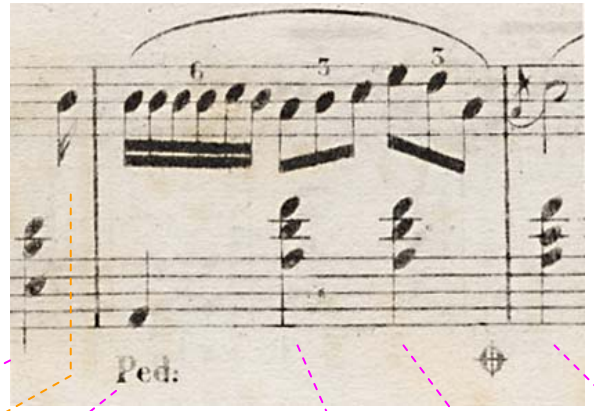
*Mz*HarmonicSpectrogram

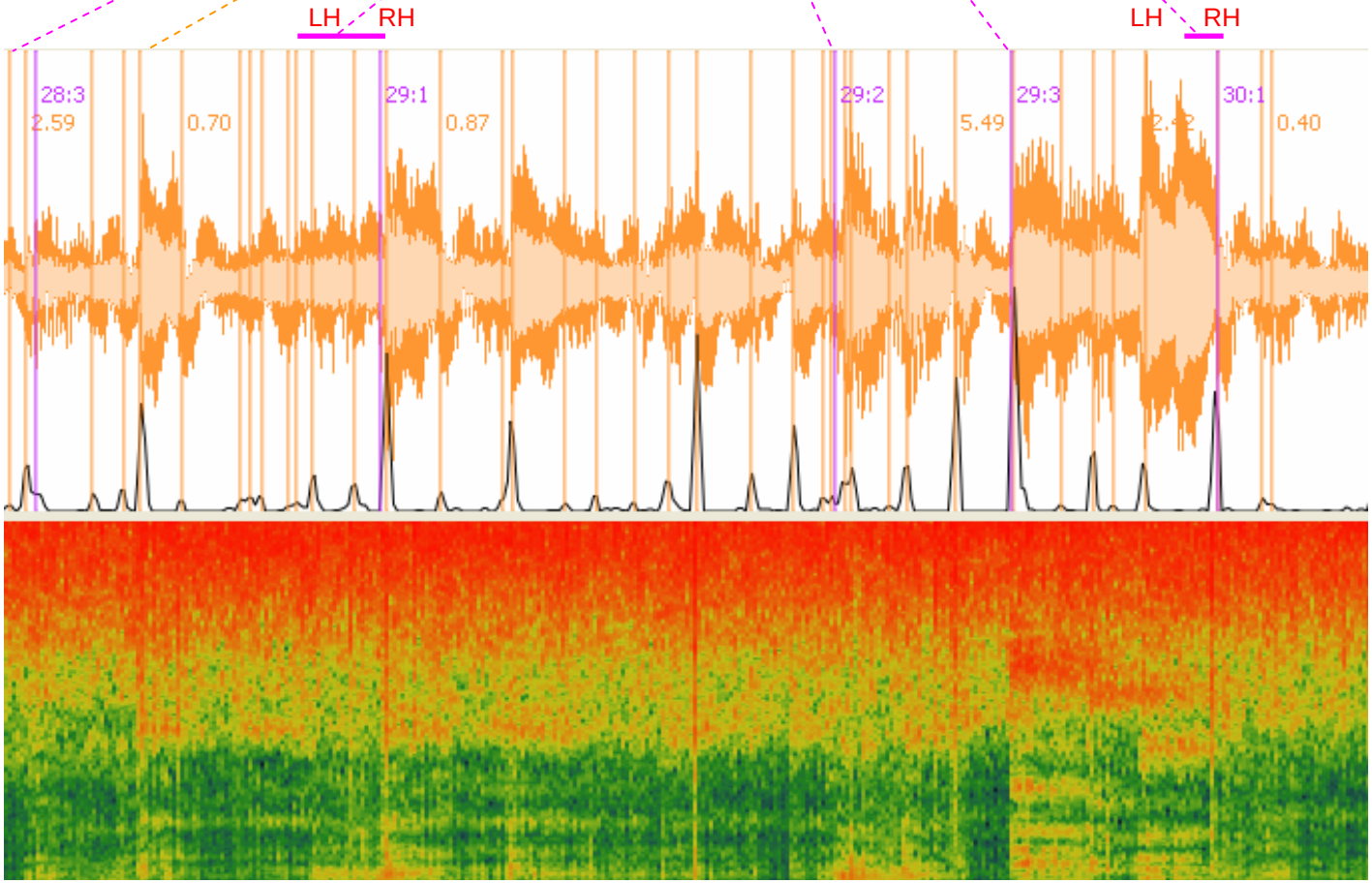
poor low freq resolution…

Misbehaved

(Risler 1920)

- pickup longer than 16th
- LH before RH
- triplets played same speed as sextuplets
- first sextuplet note longest





lots of false positives

lots of noise/clicks

Extracted Feature Data

• Further feature extraction by Andrew Earis (note timings/dynamics)

• Beat times durations or tempos

0.150	0.604	99
0.754	0.530	113
1.284	0.500	120
1.784	0.512	117
2.297	0.567	106
2.864	0.567	106
3.432	0.641	94
4.073	0.998	60
5.072	1.870	32
6.942	1.555	39
8.498	1.821	33
10.320	1.177	51
11.497	0.811	74
12.309	0.835	72
13.145	0.658	91
13.804	0.610	98
14.415	0.619	97
15.034	0.622	96
15.657	0.637	94
16.294		
(*seconds*)	(*seconds*)	(*BPM*)

http://mazurka.org.uk/info/excel/beat

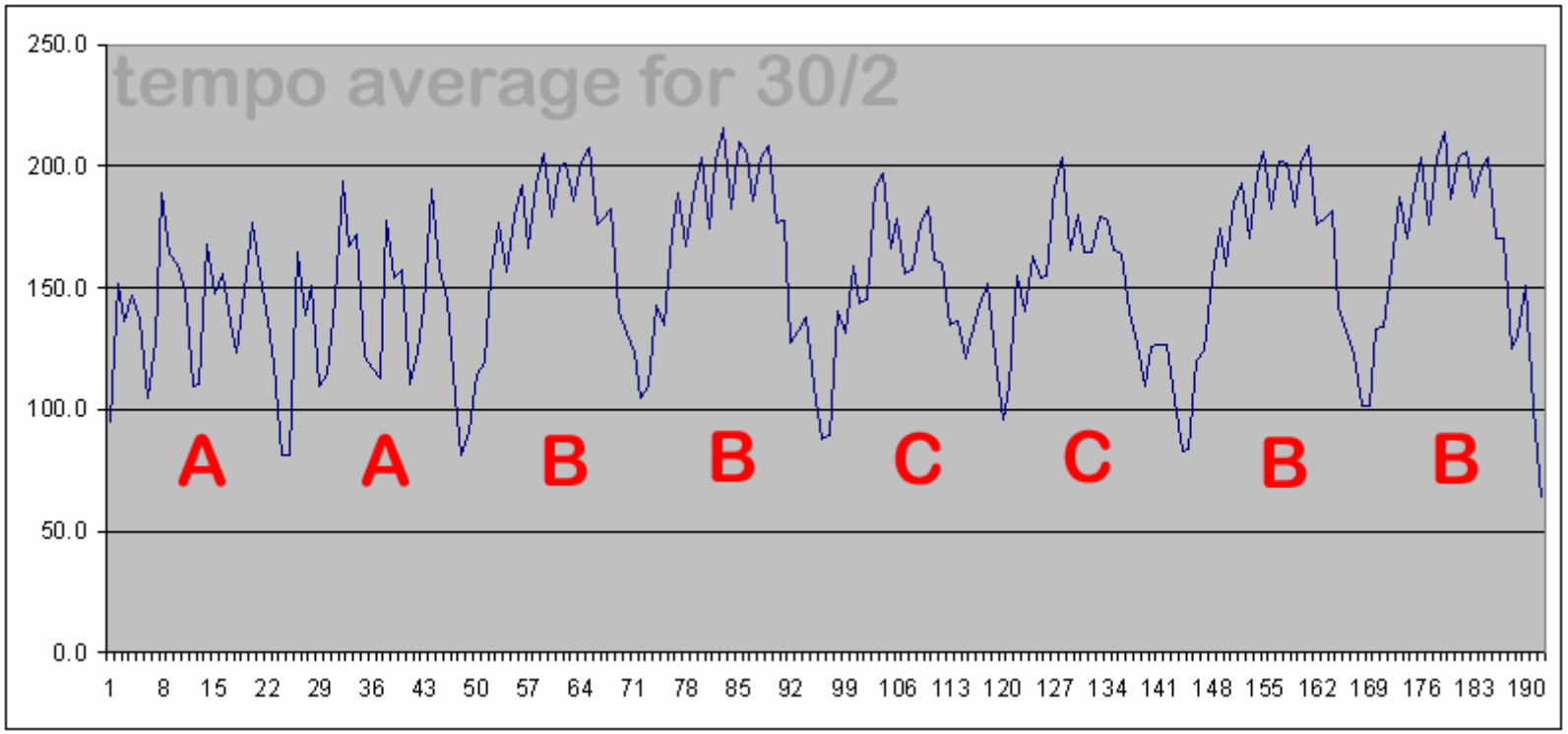
• Audio amplitude at beat locations

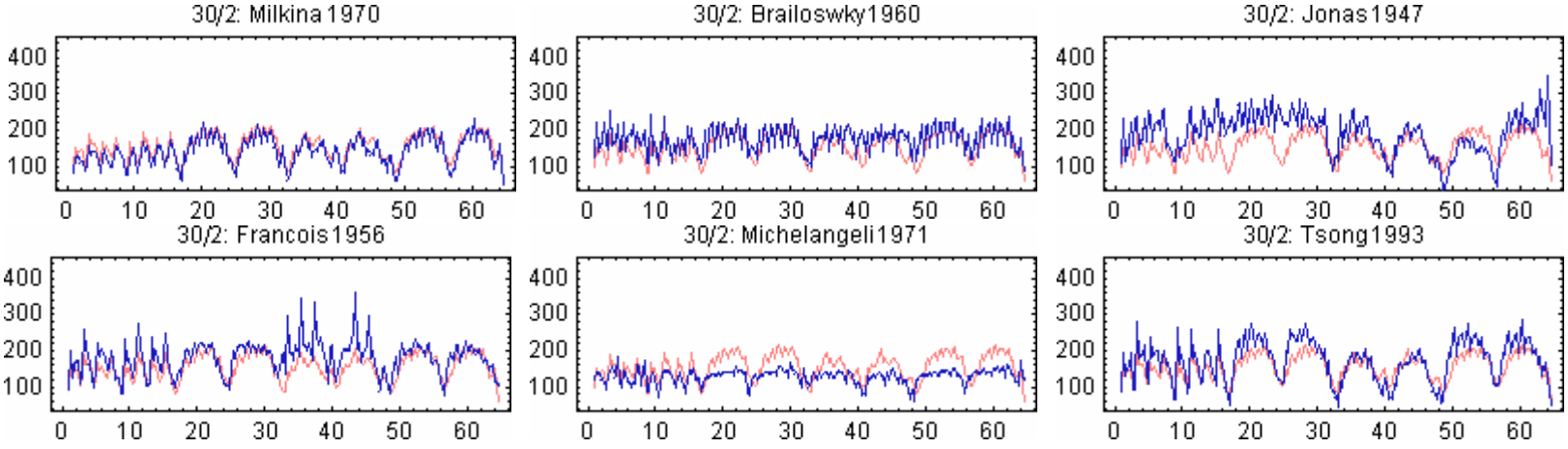
61.6
65.0
68.9
69.9
66.3
66.9
66.1
63.4
61.4
62.5
62.5
60.7
70.4
65.3
71.2
65.5
66.9
77.9
72.7
70.7
(~*dB*)

http://mazurka.org.uk/info/excel/dyn/gbdyn

http://mazurka.org.uk/ana/tempograph

Beat-Tempo Graphs

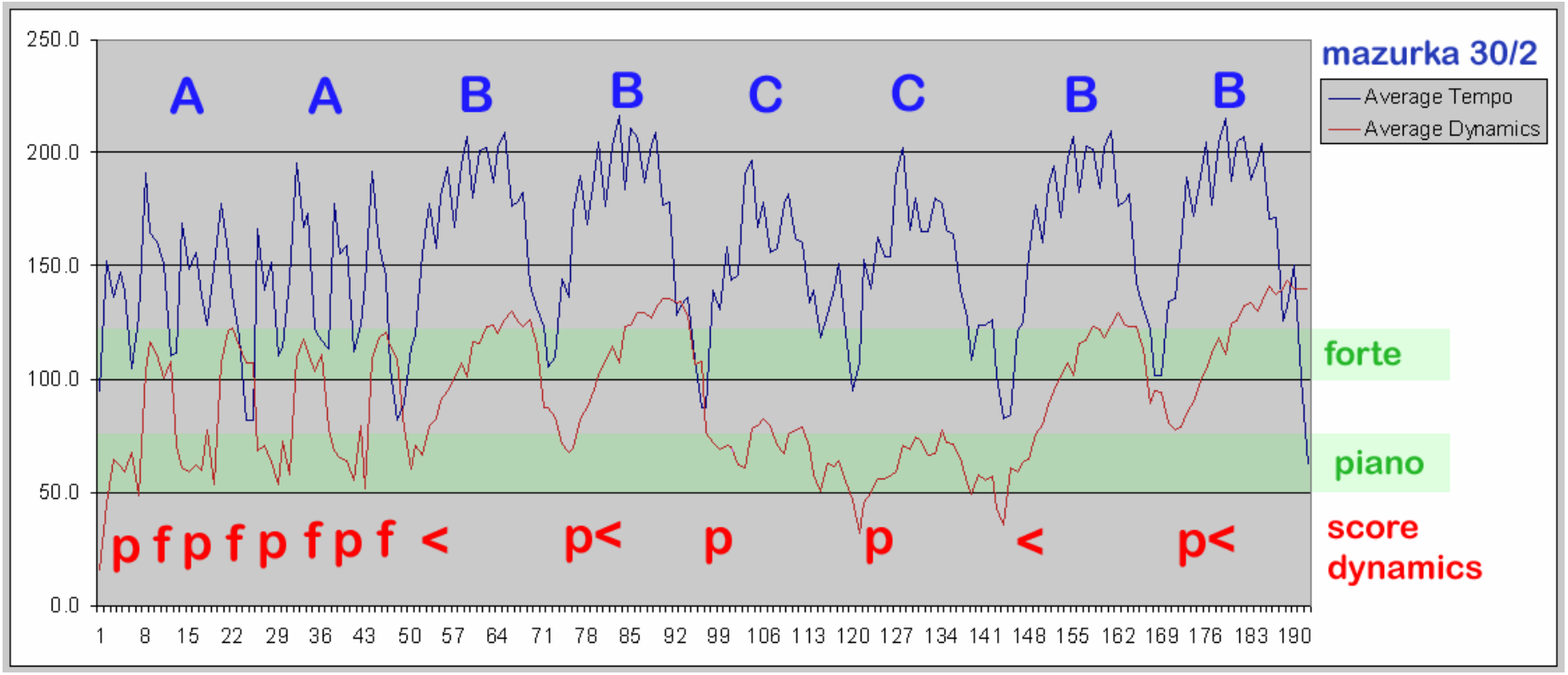


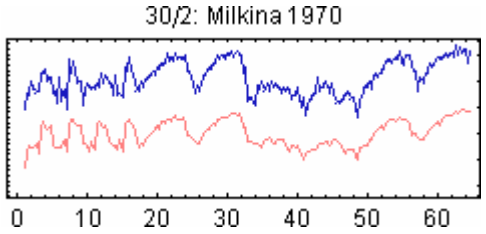


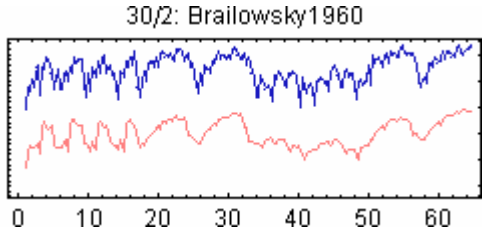
average

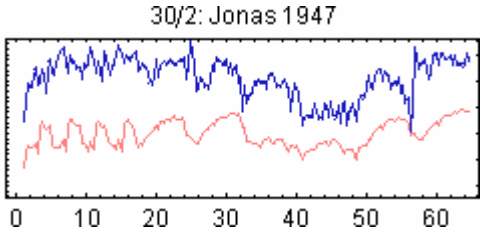
http://mazurka.org.uk/ana/dyngraph

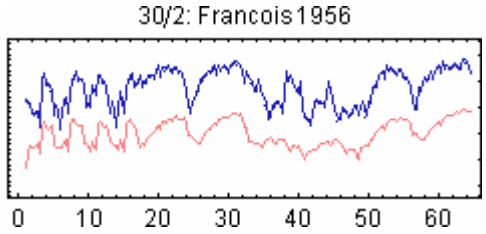
Beat-Dynamics Graphs

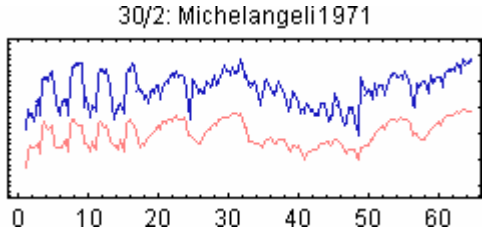


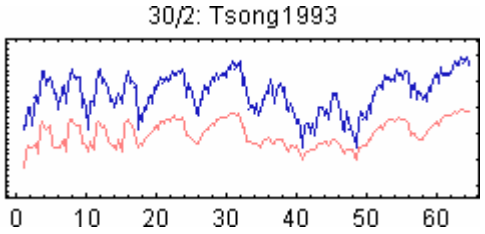












average

Pearson Correlation

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$$

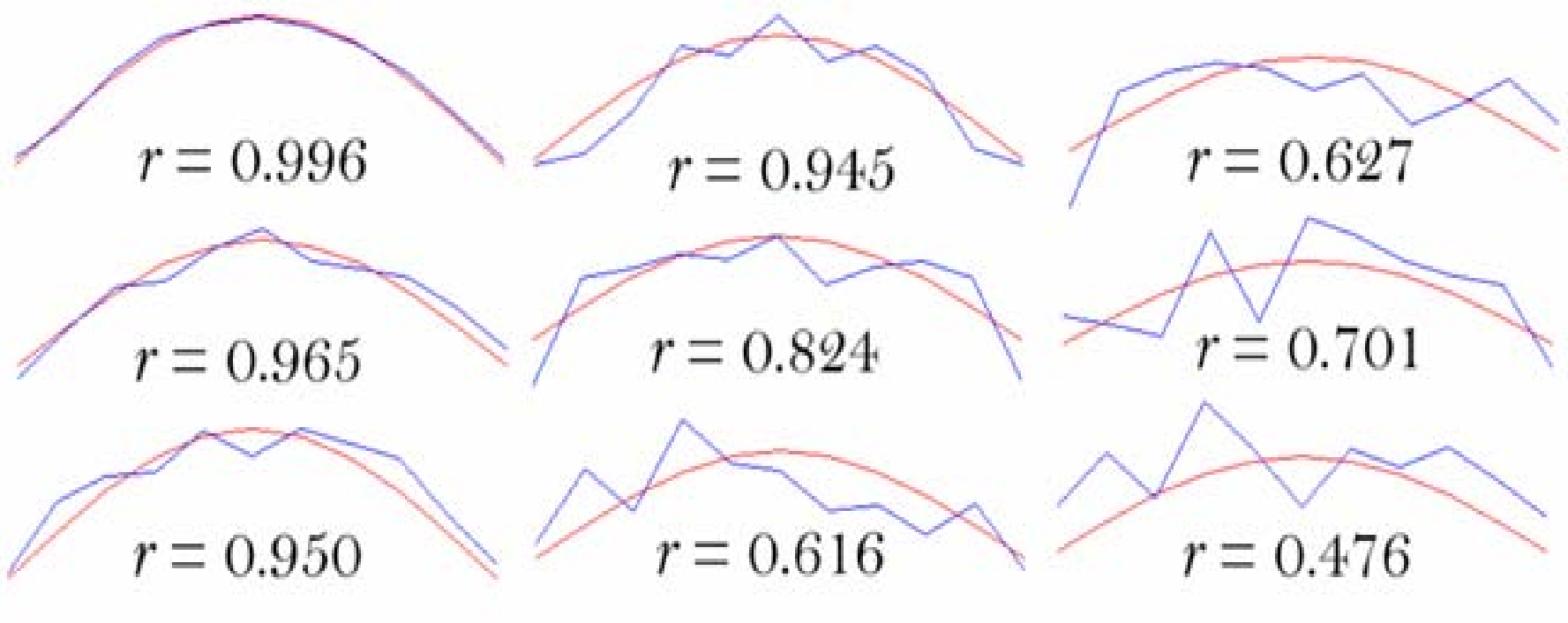
Example:

x = (1,3,4,2,7,4,2,3,1) y = (4,4,3,5,5,6,4,3,2)

$\overline{x} = 3$ (average of x) $\overline{y} = 4$ (average of y)

$r = 0.436436$

Shape Matching



Correlation & Fourier Analysis

correlation: multiply & sum

$$\underbrace{X(k)}_{\text{spectrum}} = \sum_{n} \underbrace{x(n)}_{\text{signal}} \underbrace{e^{-2\pi jnk}}_{\text{sinusoids}}$$

$X(k)$ = spectrum, indexed by *k* (frequency)

$x(n)$ = signal, indexed by *n* (time)

$e^{-2\pi jnk}$ = set of *k* complex sinusoids indexed by *n*

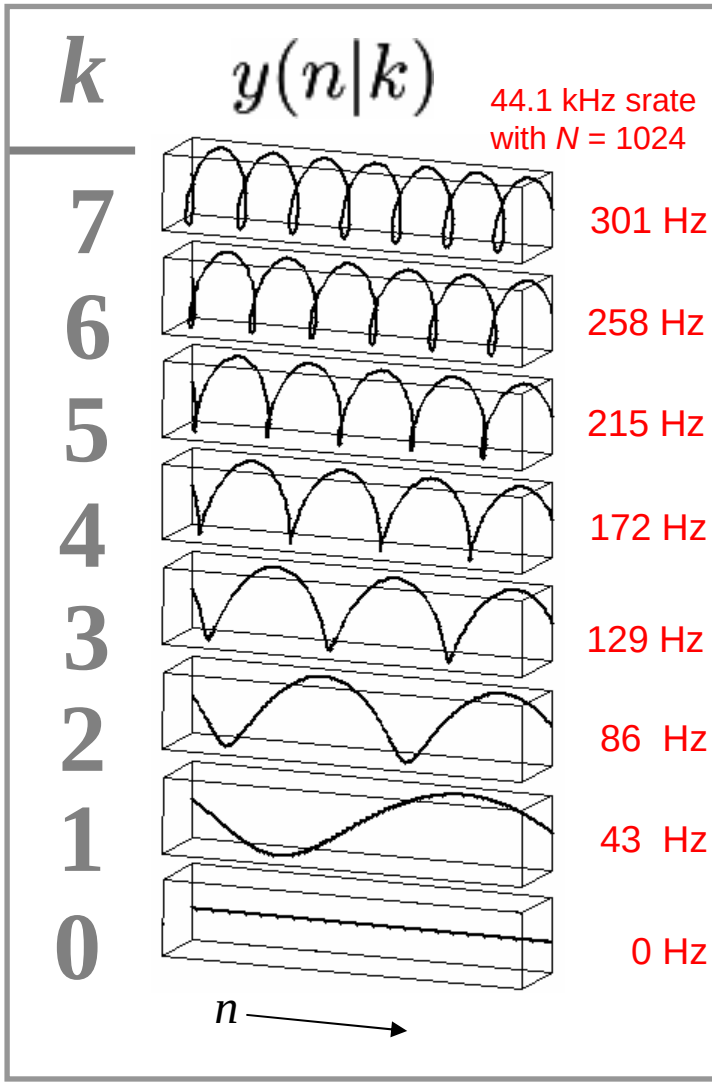
Correlation & Fourier Analysis (2)

Let $y(n|k) = e^{-2\pi jnk}$

Then the DFT can then be written as:

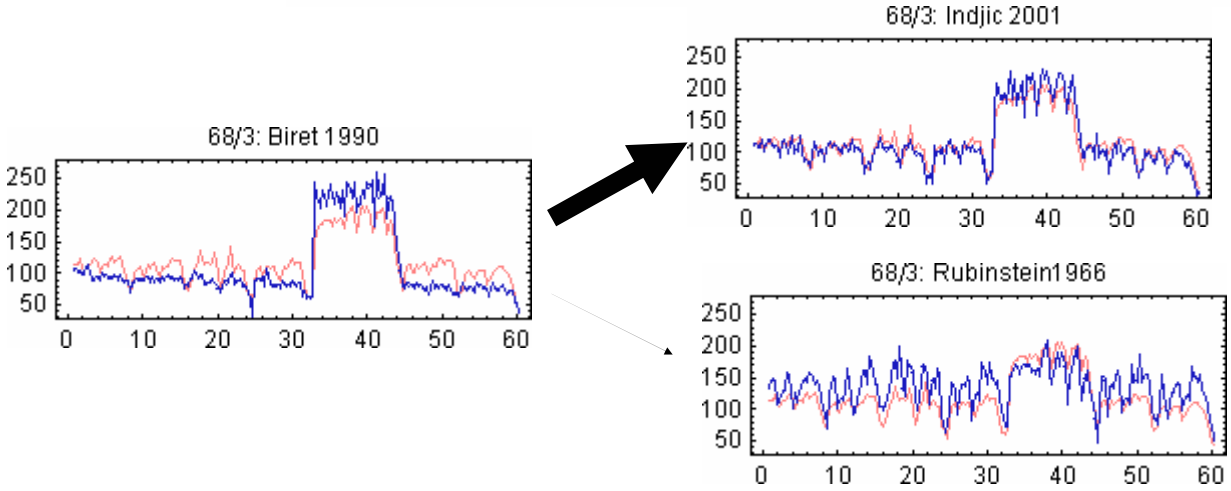
$$X(k) = \sum_n x(n)\ y(n|k)$$

$$X \begin{cases} \cdots \\ X_3 = \sum x(n)\ y_3(n) \\ X_2 = \sum x(n)\ y_2(n) \\ X_1 = \sum x(n)\ y_1(n) \\ X_0 = \sum x(n)\ y_0(n) \end{cases}$$



Performance Tempo Correlations

	Bi	Br	Ch	Fl	In	Lu	R8	R6	Sm	Un
Biret	1.	0.92	0.81	0.83	0.95	0.85	0.62	0.5	0.55	0.86
Brailowsky	0.92	1.	0.81	0.86	0.91	0.84	0.66	0.55	0.65	0.85
Chiu	0.81	0.81	1.	0.86	0.86	0.81	0.76	0.74	0.67	0.89
Friere	0.83	0.86	0.86	1.	0.88	0.84	0.73	0.7	0.74	0.89
Indjic	0.95	0.91	0.86	0.88	1.	0.88	0.66	0.59	0.63	0.9
Luisada	0.85	0.84	0.81	0.84	0.88	1.	0.67	0.61	0.56	0.89
Rubinstein 1938	0.62	0.66	0.76	0.73	0.66	0.67	1.	0.77	0.62	0.75
Rubinstein 1966	0.5	0.55	0.74	0.7	0.59	0.61	0.77	1.	0.59	0.69
Smith	0.55	0.65	0.67	0.74	0.63	0.56	0.62	0.59	1.	0.64
Uninsky	0.86	0.85	0.89	0.89	0.9	0.89	0.75	0.69	0.64	1.



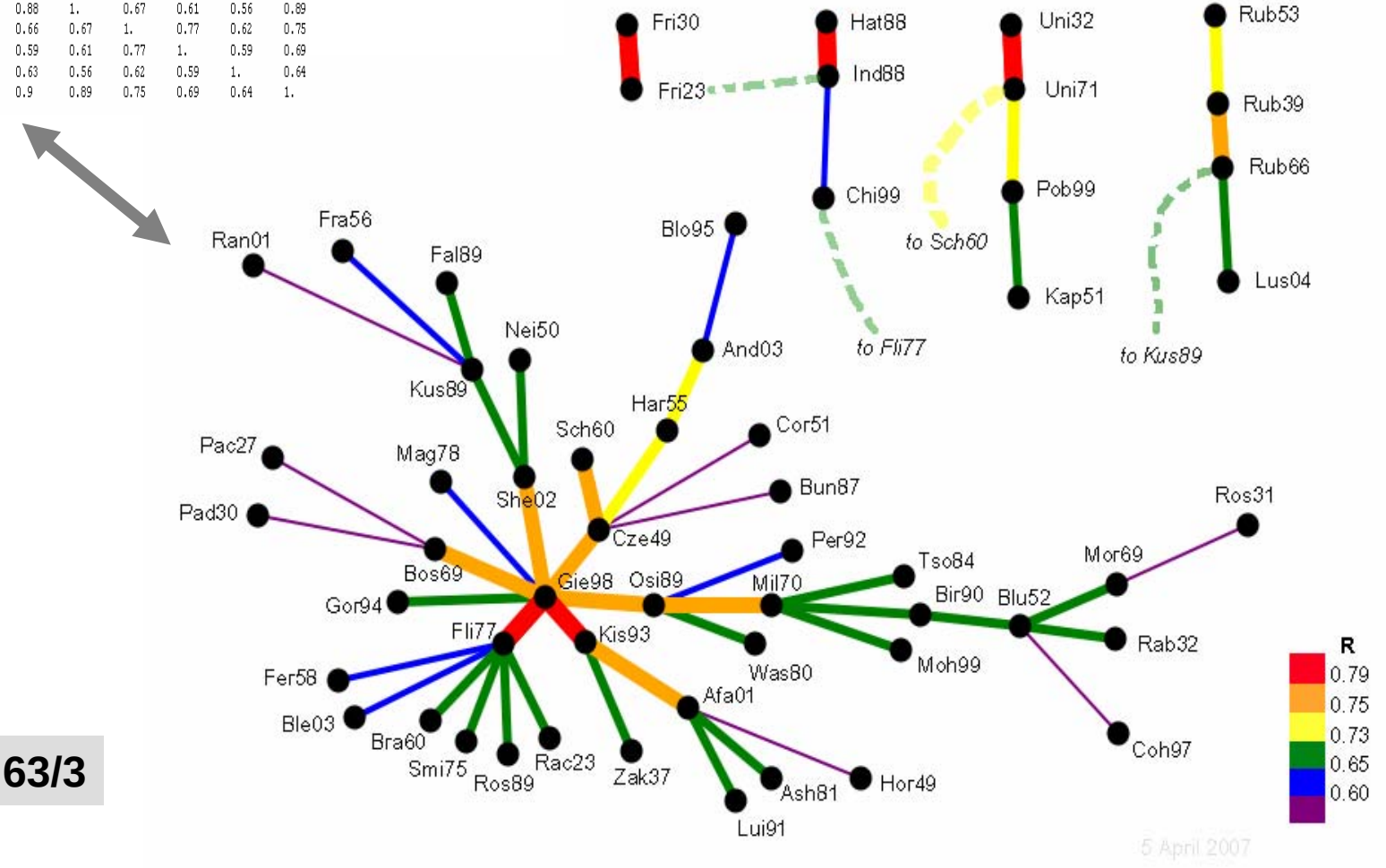
Highest correlation to Biret

Lowest correlation to Biret

Correlation Maps – Nearest Neighbor

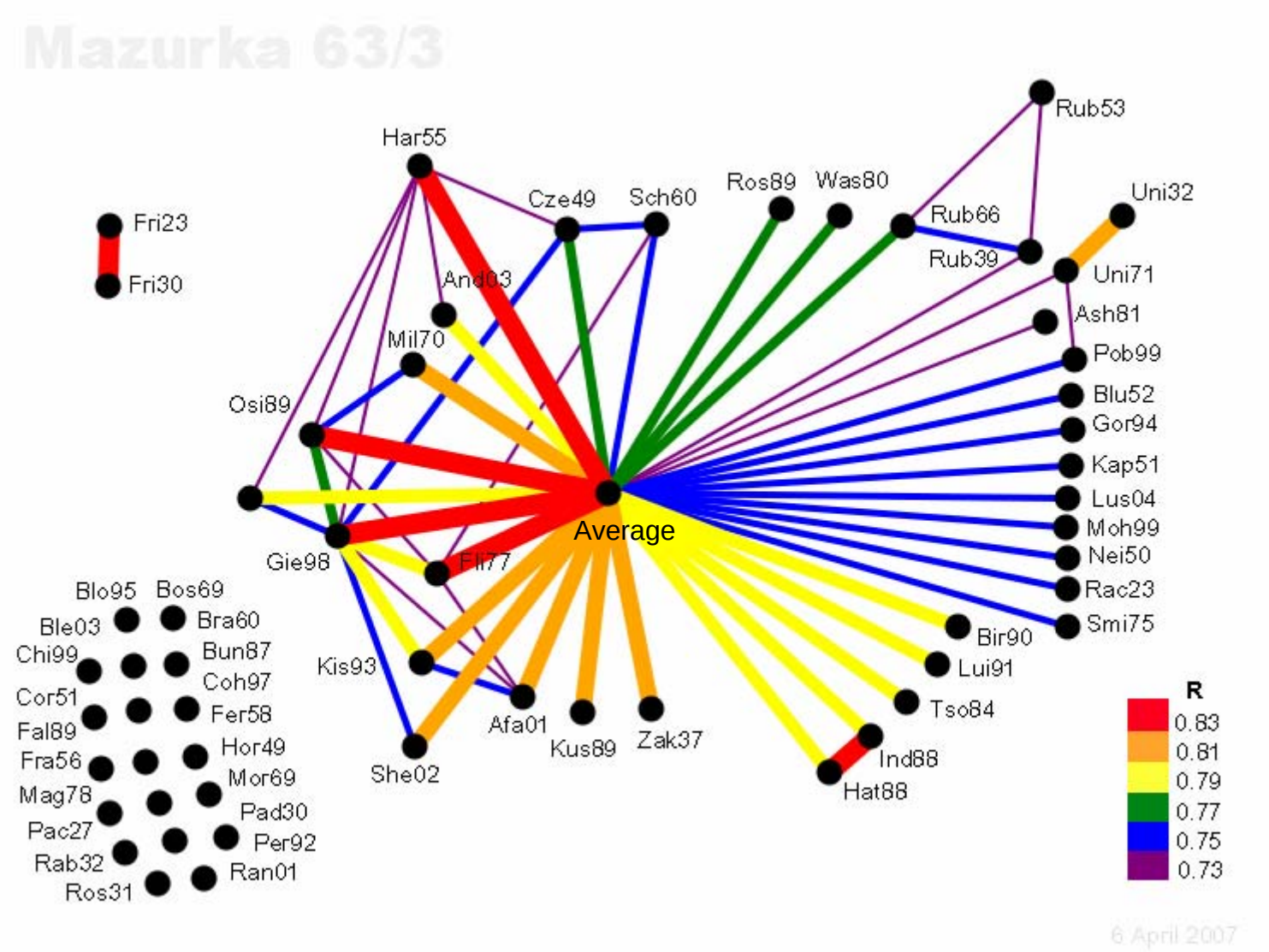
- Draw one line connecting each performance to its closest correlation match
- Correlating to the entire performance length.

1.	0.92	0.81	0.83	0.95	0.85	0.62	0.5	0.55	0.86
0.92	1.	0.81	0.86	0.91	0.84	0.66	0.55	0.65	0.85
0.81	0.81	1.	0.86	0.86	0.81	0.76	0.74	0.67	0.89
0.83	0.86	0.86	1.	0.88	0.84	0.73	0.7	0.74	0.89
0.95	0.91	0.86	0.88	1.	0.88	0.66	0.59	0.63	0.9
0.85	0.84	0.81	0.84	0.88	1.	0.67	0.61	0.56	0.89
0.62	0.66	0.76	0.73	0.66	0.67	1.	0.77	0.62	0.75
0.5	0.55	0.74	0.7	0.59	0.61	0.77	1.	0.59	0.69
0.55	0.65	0.67	0.74	0.63	0.56	0.62	0.59	1.	0.64
0.86	0.85	0.89	0.89	0.9	0.89	0.75	0.69	0.64	1.



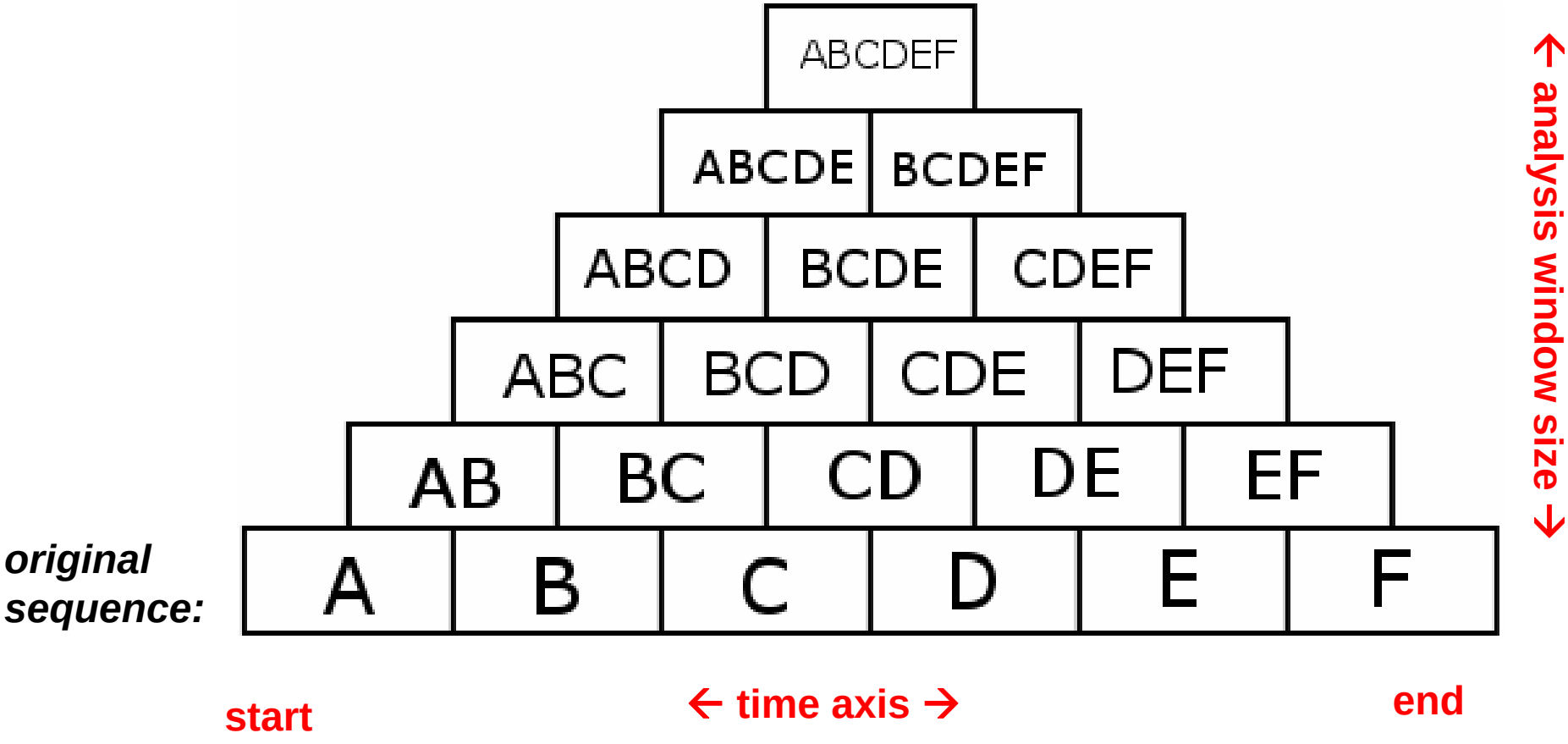
Mazurka 63/3

Absolute Correlation Map



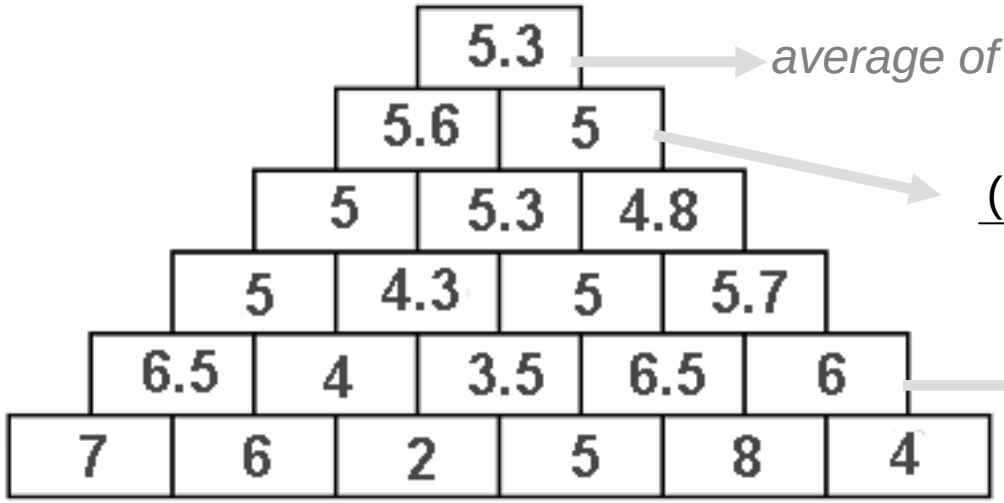
Scape Plotting Domain

- 1-D data sequences chopped up to form a 2-D plot
- Example of a composition with 6 beats at tempos A, B, C, D, E, and F:



Scape Plotting Example

- Averaging in each cell with base sequence (7,8,2,5,8,4):



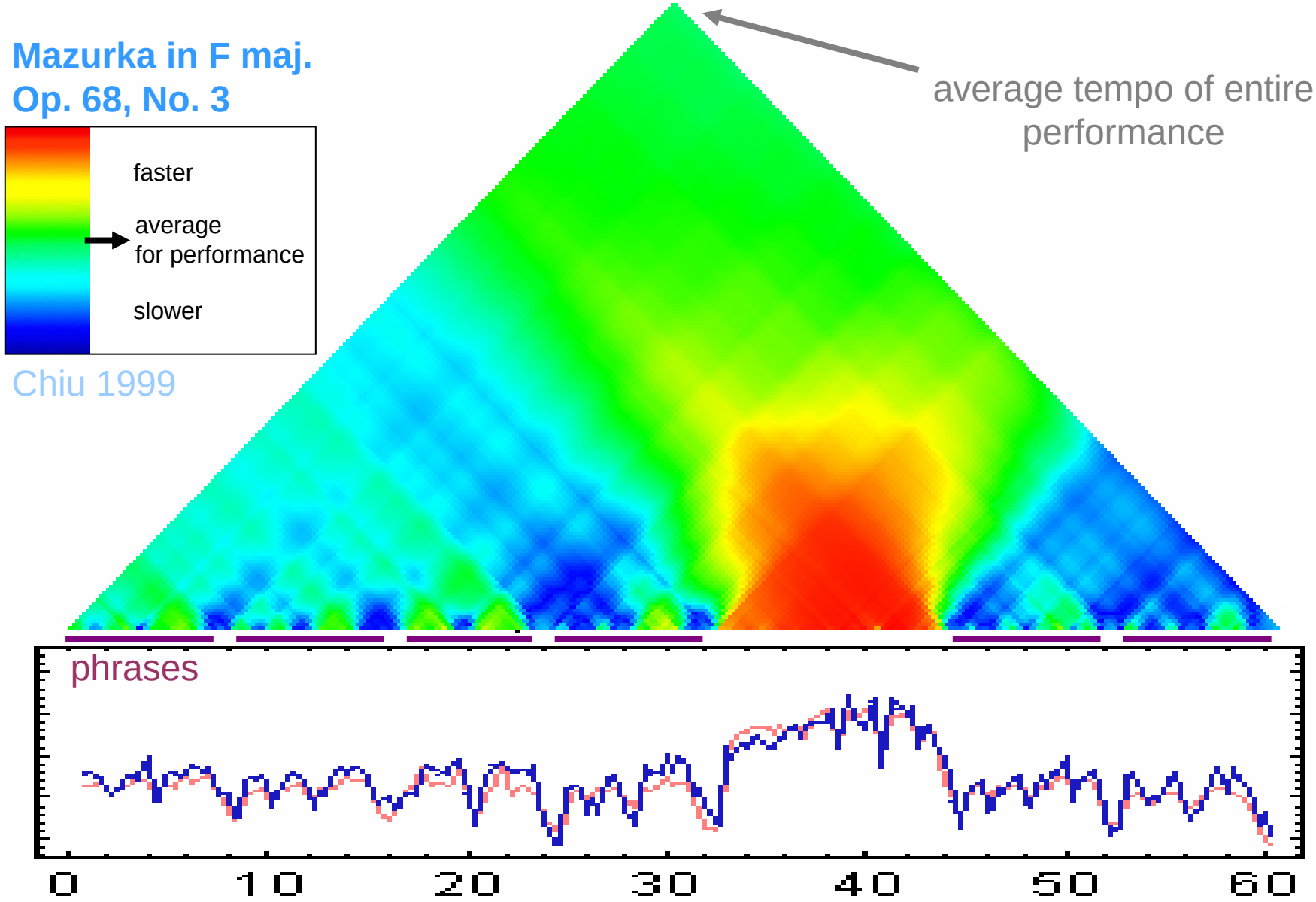
average of all 6 numbers at bottom

$$\frac{(6+2+5+8+4)}{5} = \frac{25}{5} = 5$$

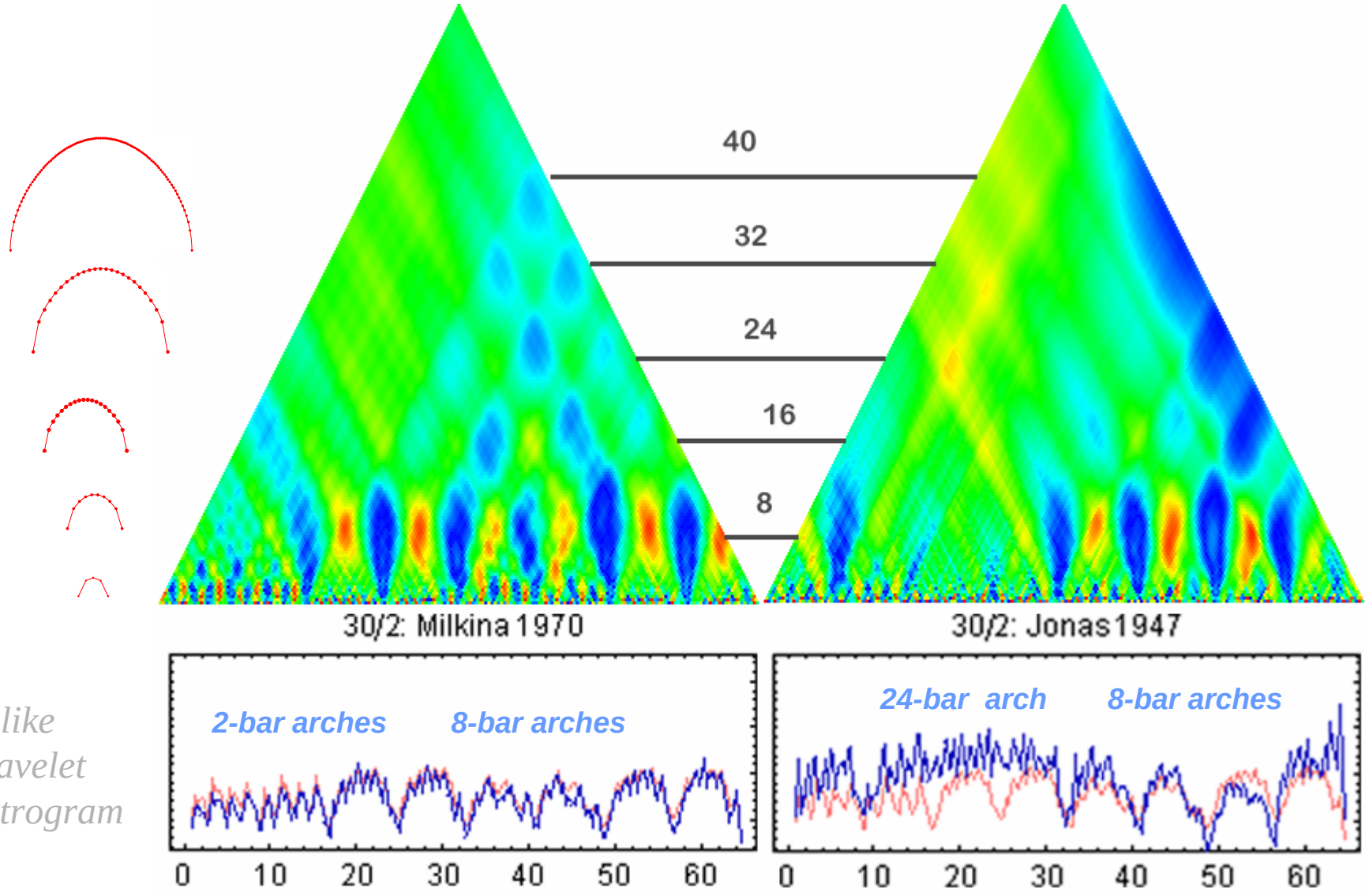
average of last 5 numbers

$$\frac{(8+4)}{2} = \frac{12}{2} = 6$$

Average-Tempo Timescapes



Arch Correlation Scapes



like wavelet spectrogram

Composite Features

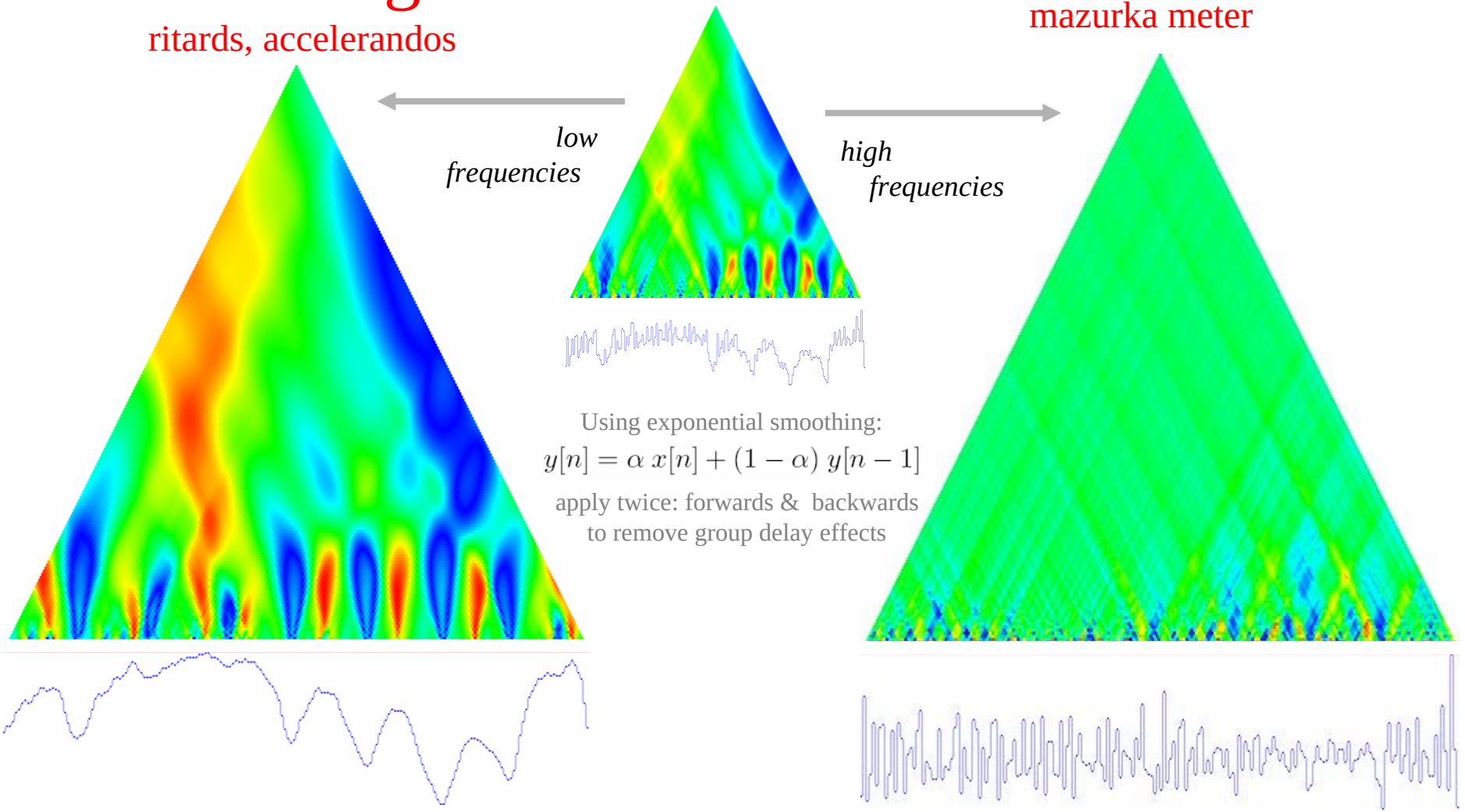
multiple performance features embedded in data

Phrasing

ritards, accelerandos

Accentuation

mazurka meter

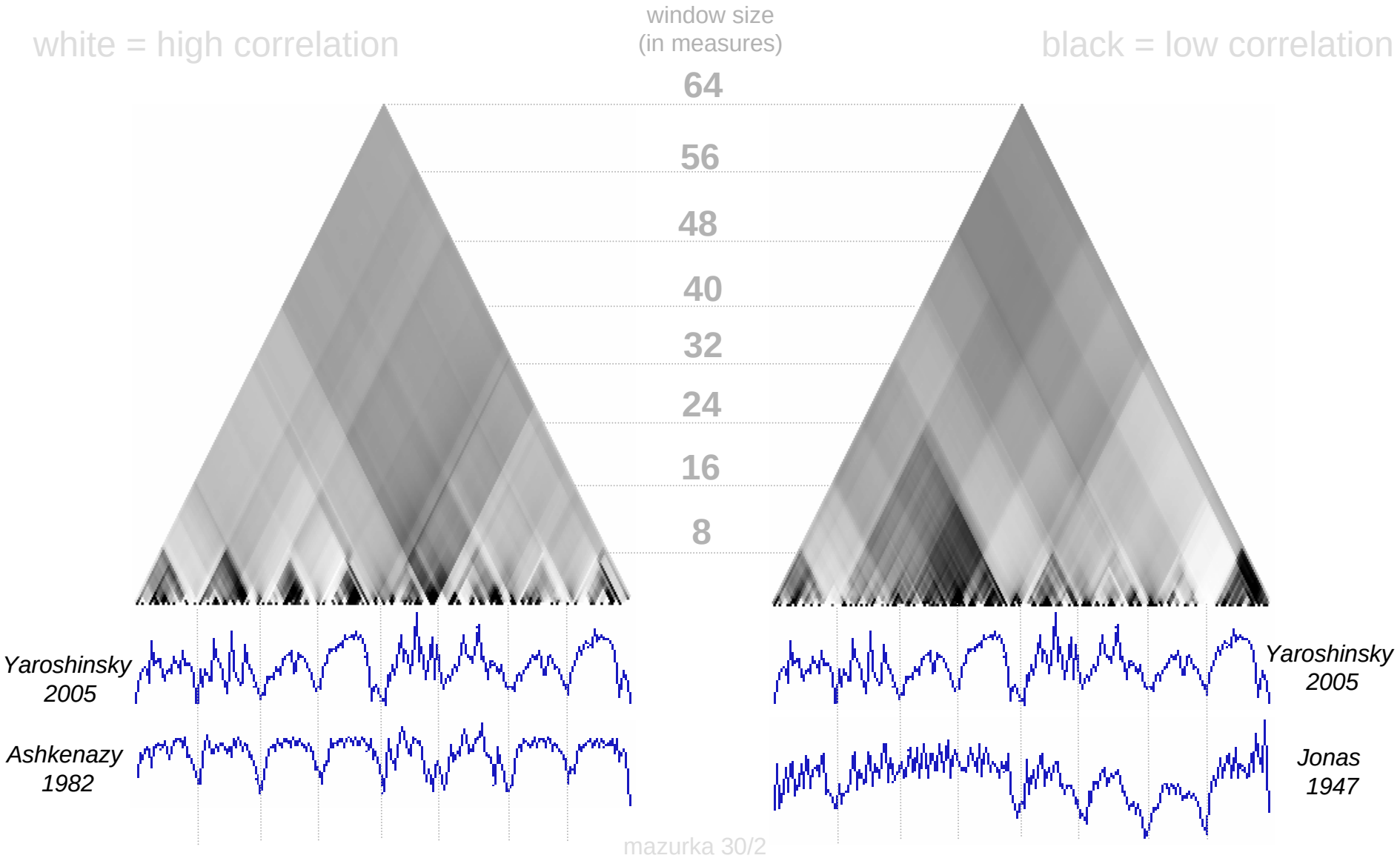


Using exponential smoothing:

$$y[n] = \alpha\, x[n] + (1-\alpha)\, y[n-1]$$

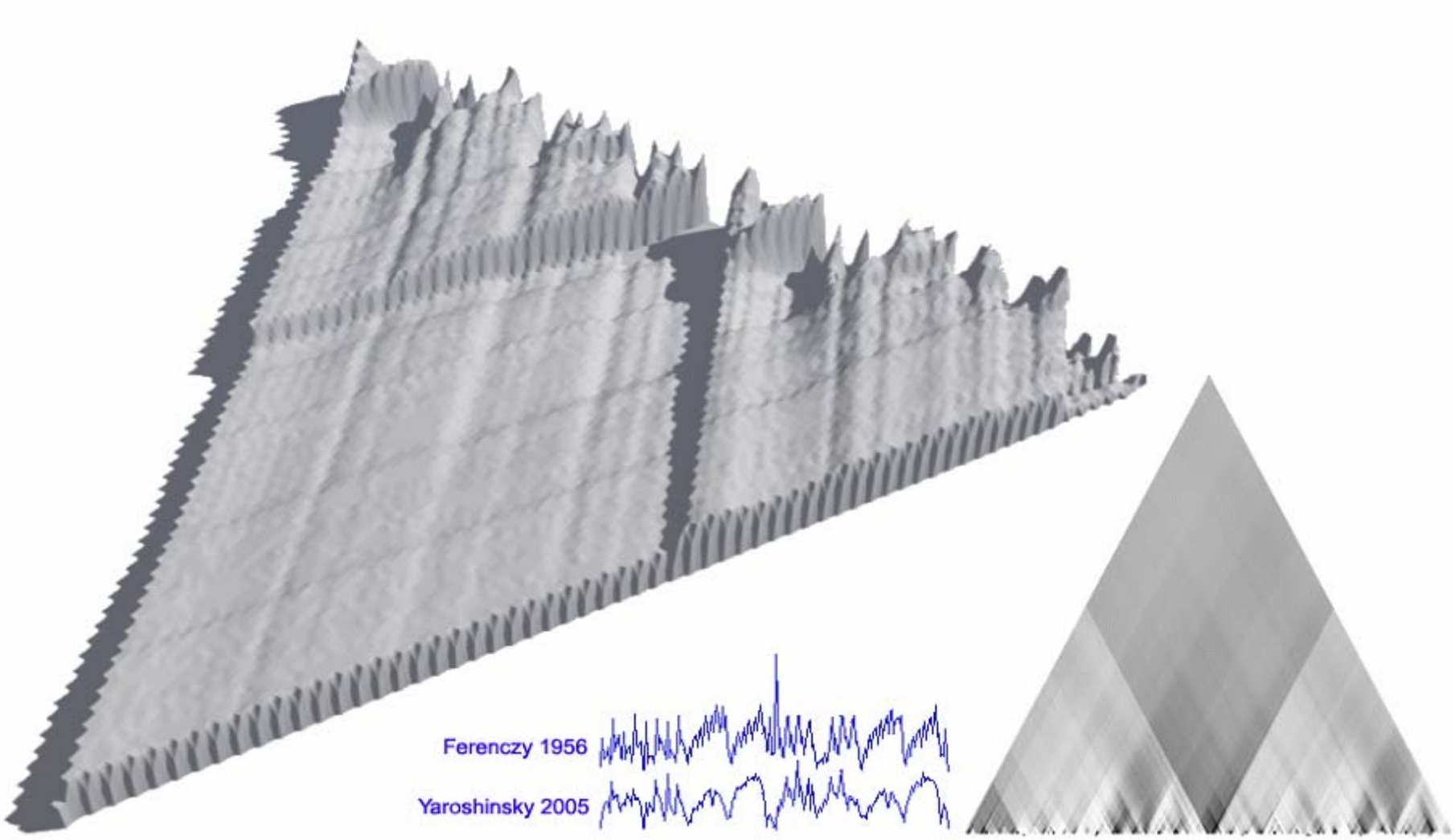
apply twice: forwards & backwards
to remove group delay effects

Binary Correlation Scapes

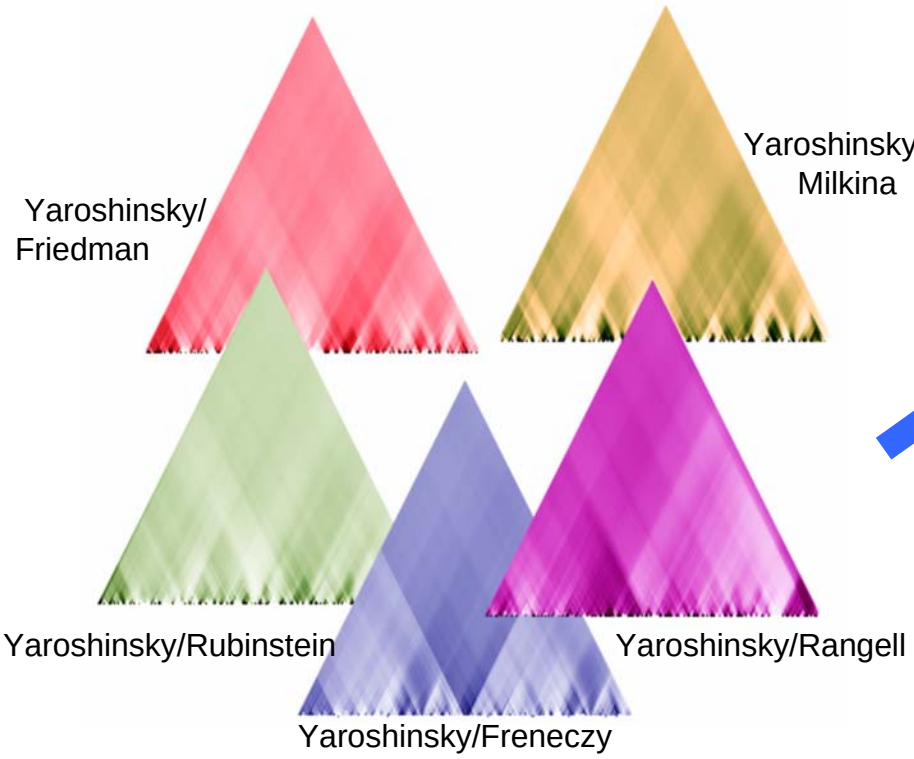


Scapes Are 3D Plots

2D plotting domain + 1D plotting range

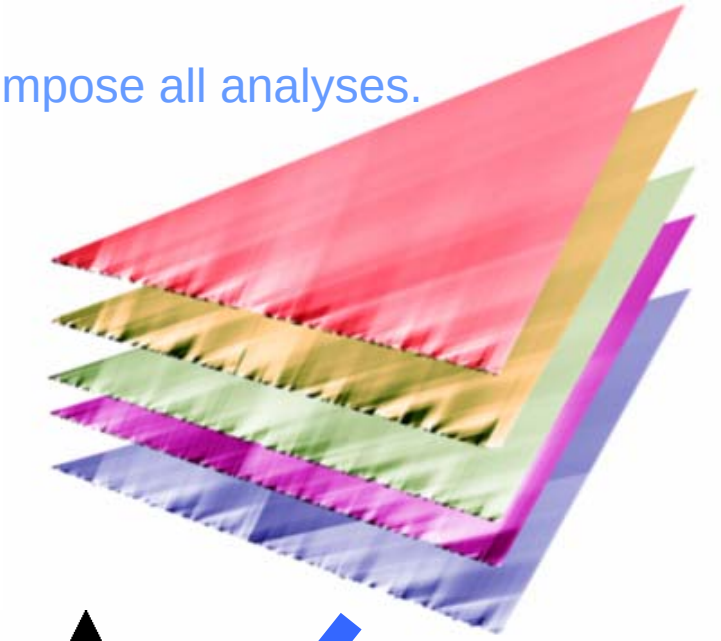


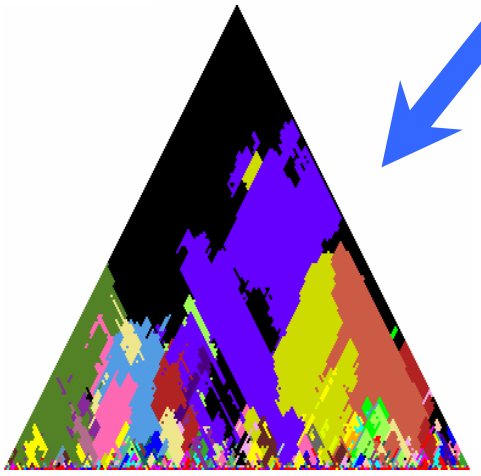
Scapes of Multiple Performances



1. correlate one performance to all others – assign unique color to each comparison.

2. superimpose all analyses.

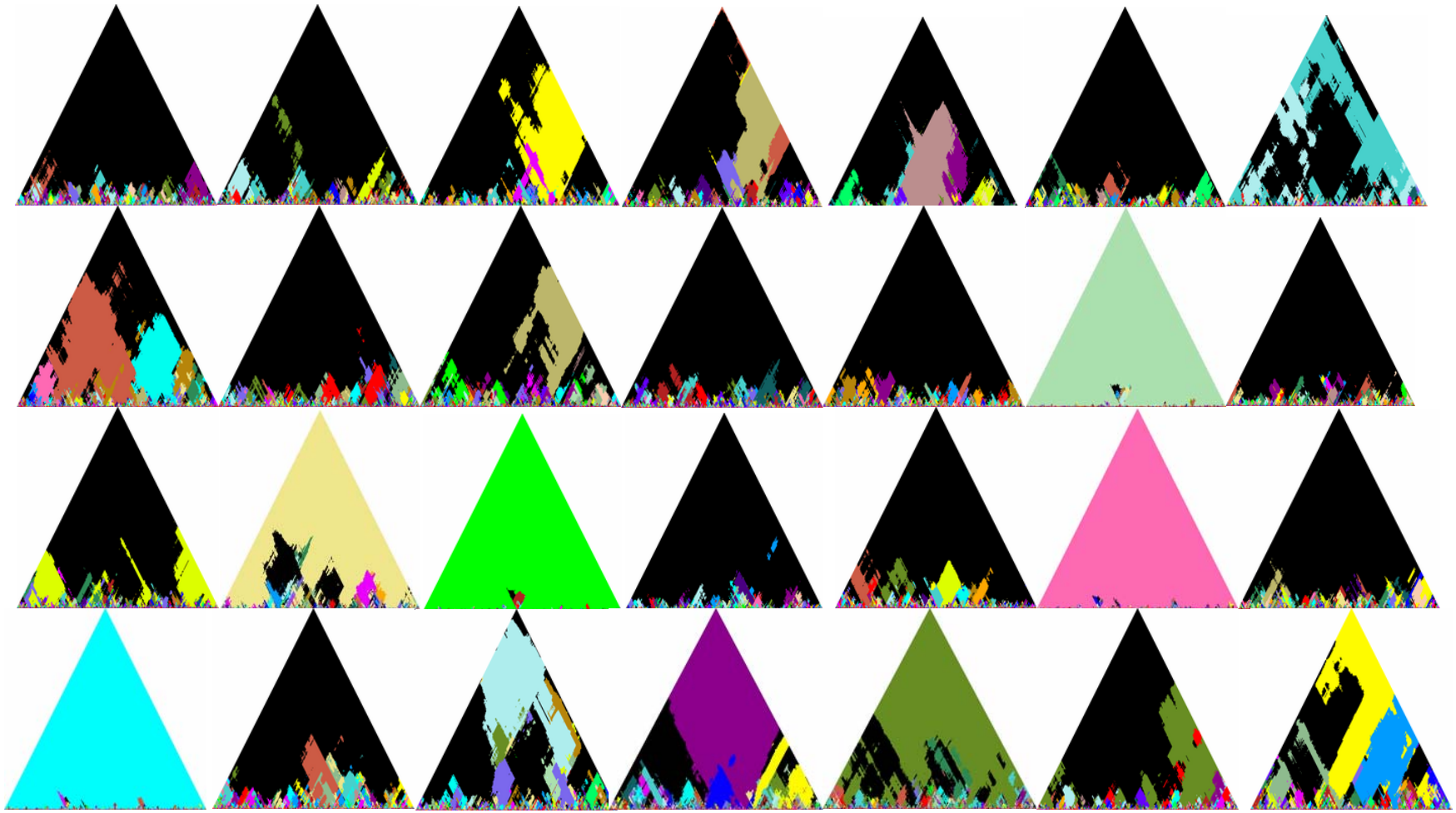




3. look down from above at highest peaks

Perormance Correlation Scapes

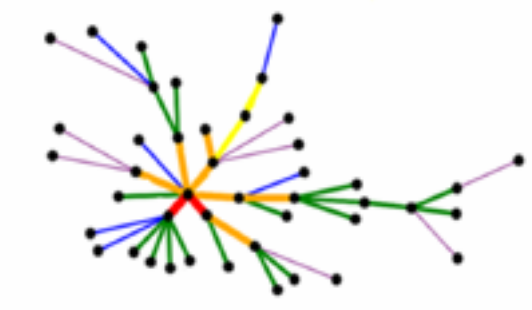
- **Who is most similar to a particular performer at any given region in the music?**



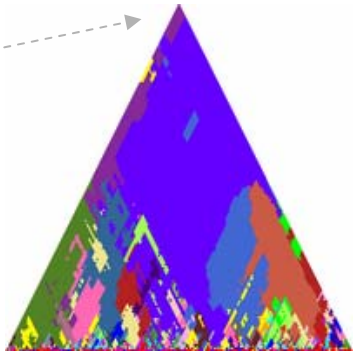
mazurka.org.uk/ana/pcor

mazurka.org.uk/ana/pcor-gbdyn

Maps and Scapes



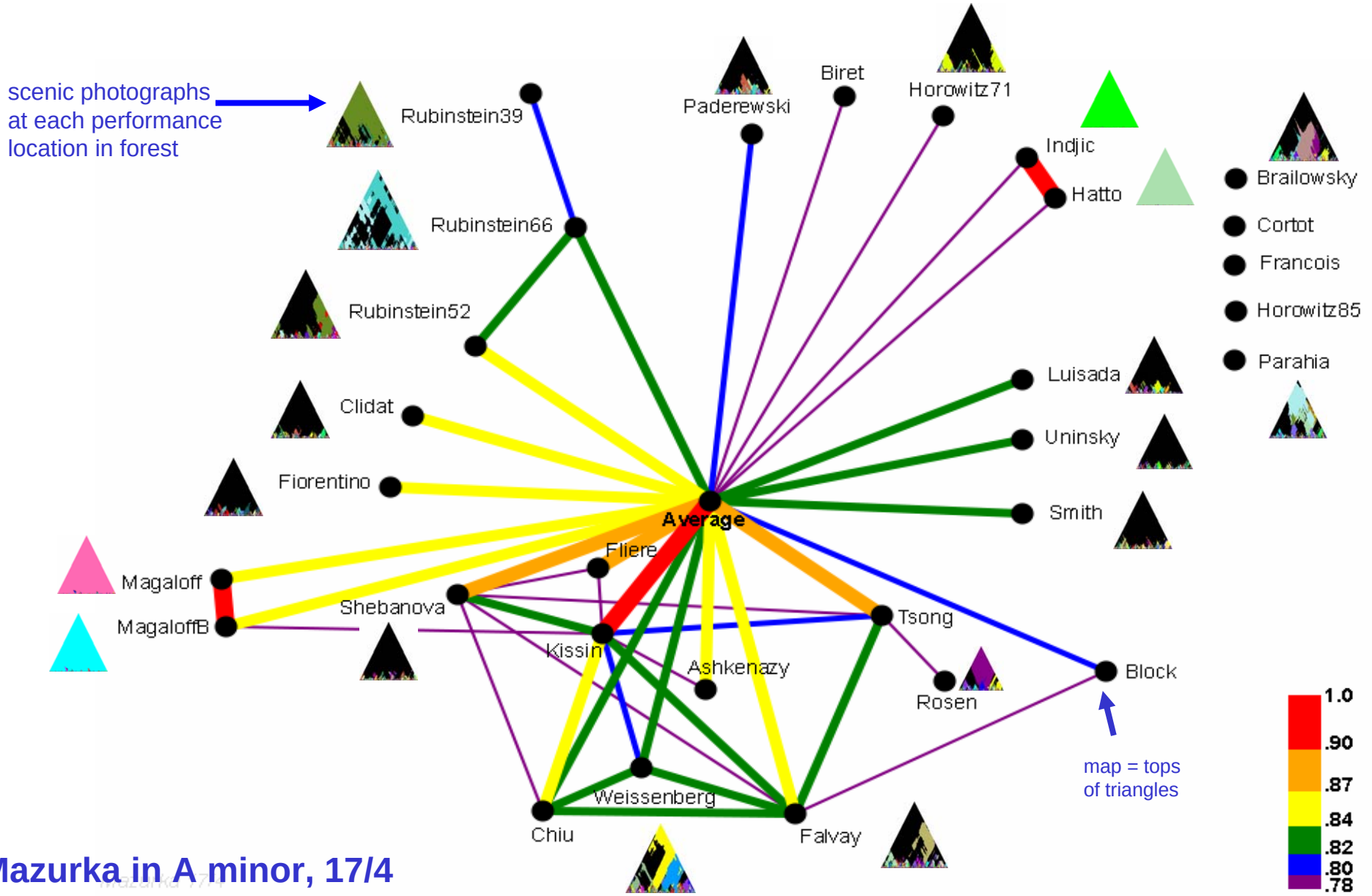
map points are tops of scapes



Correlation maps give gross detail, like a real map:

Correlation scapes give local details, like a photograph:

Map and Photos of the Forest



Mazurka in A minor, 17/4

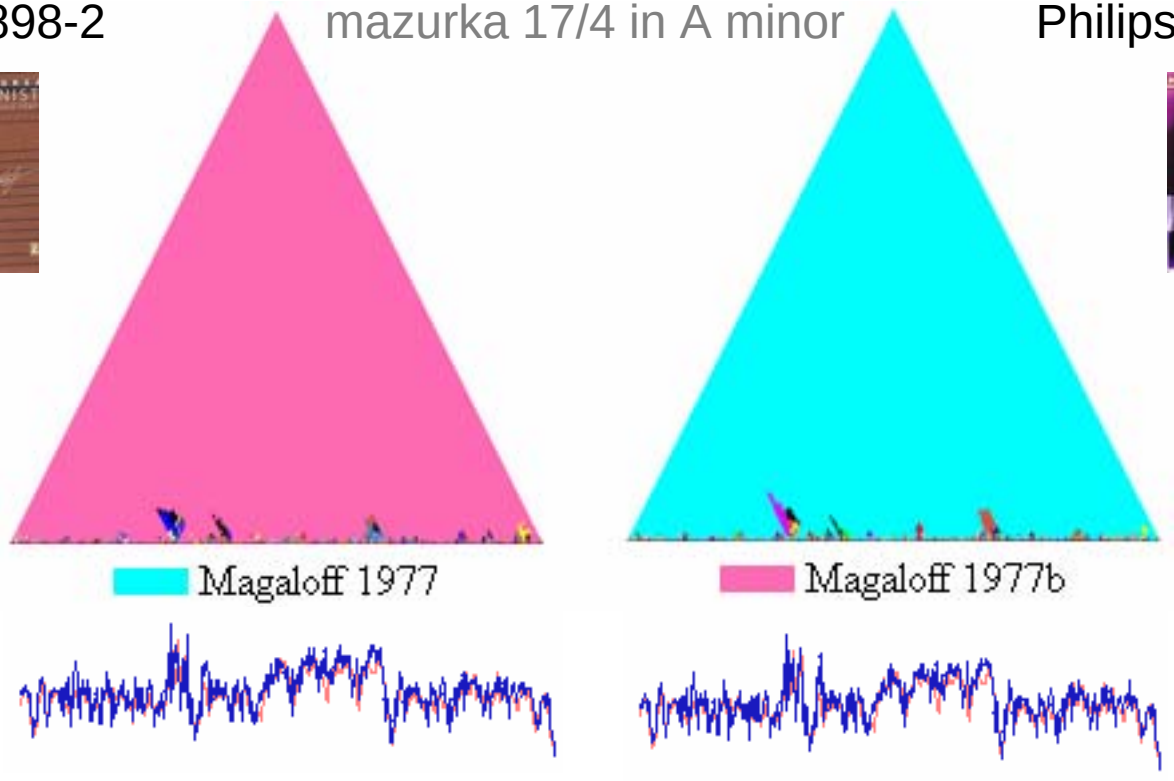
Boring Timescape Pictures

Occasionally we get over-exposed photographs back from the store, and we usually have to throw them in the waste bin.

The same performance by Magaloff on two different CD re-releases:

Philips 456 898-2

mazurka 17/4 in A minor



Philips 426 817/29-2

• Structures at bottoms due to errors in beat extraction, measuring limits in beat extraction, and correlation graininess.

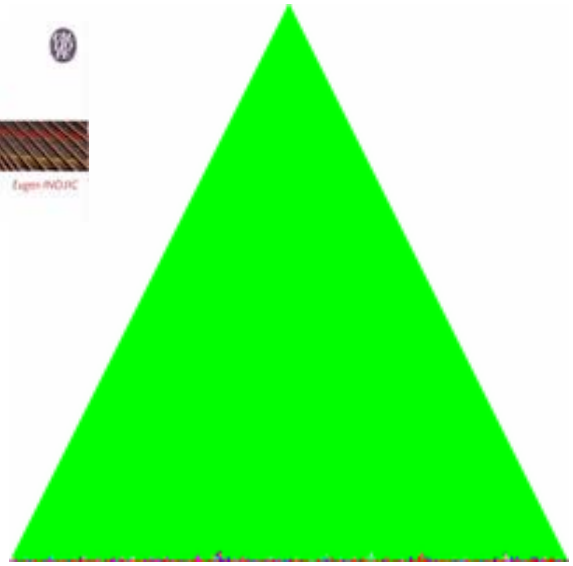
Boring Timescape Pictures?

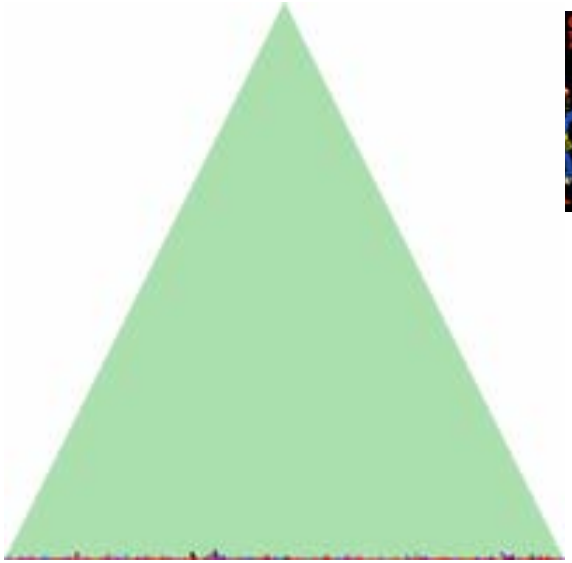
Two difference performances from two different performers on two different record labels from two different countries.

Calliope 3321

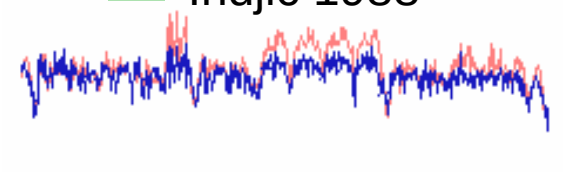
mazurka 17/4 in A minor

Concert Artist 20012

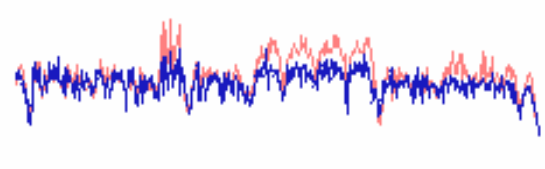




Indjic 1988



Hatto 1997



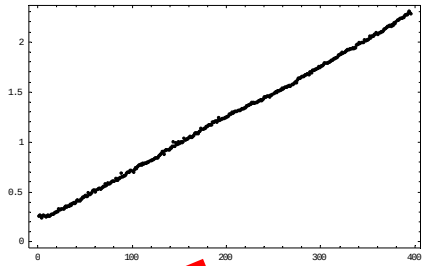
see: http://www.charm.rhul.ac.uk/content/contact/hatto_article.html

Beat-Event Timing Differences

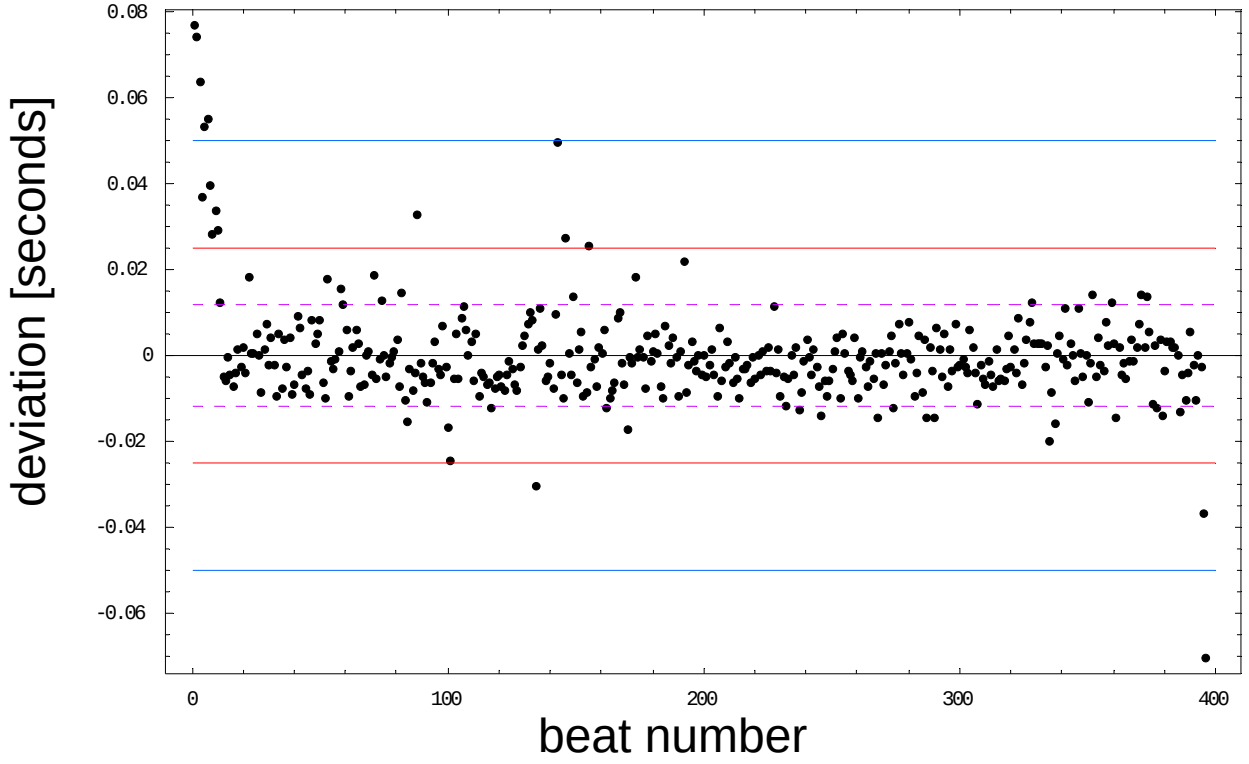
Hatto beat location times: 0.853, 1.475, 2.049, 2.647, 3.278, etc.

Indjic beat location times: 0.588, 1.208, 1.788, 2.408, 3.018, etc.

difference plot

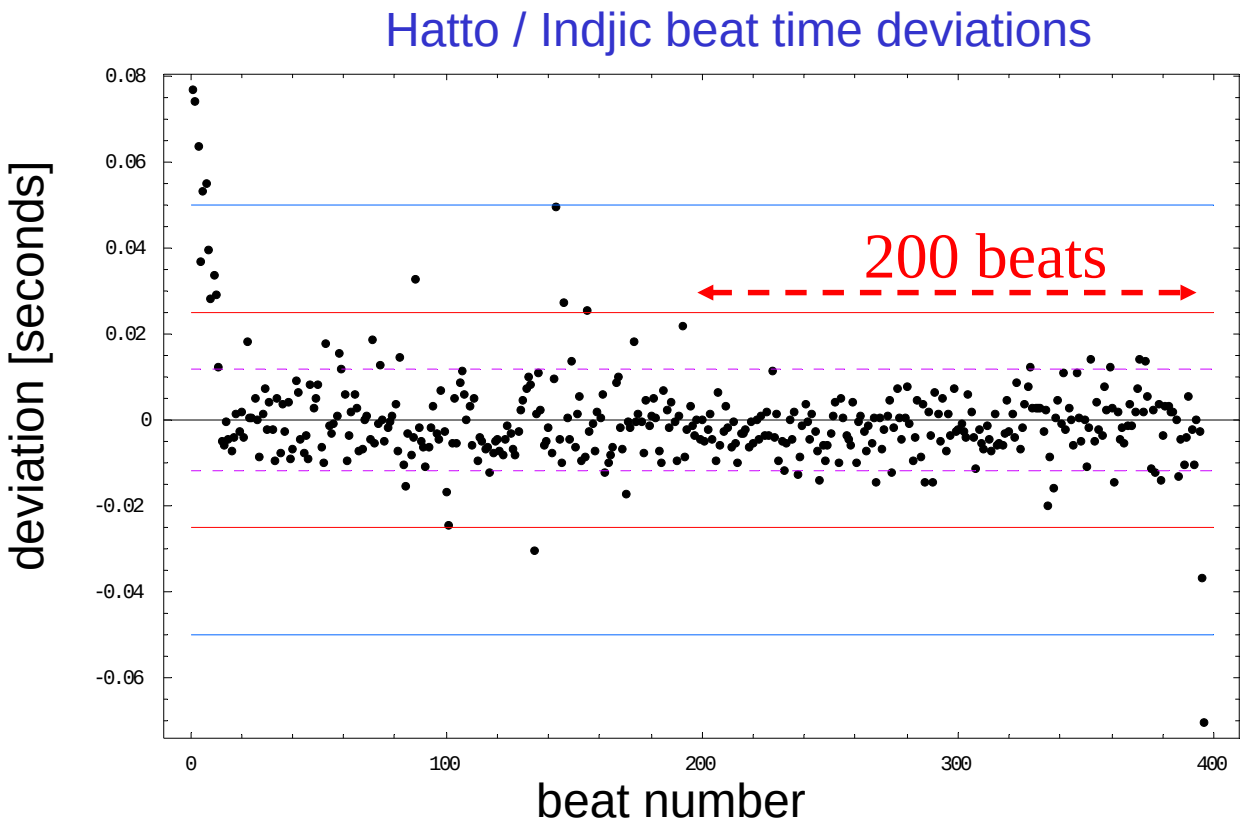


Hatto / Indjic beat time deviations



remove
0.7%
timeshift

Timing Difference Probability



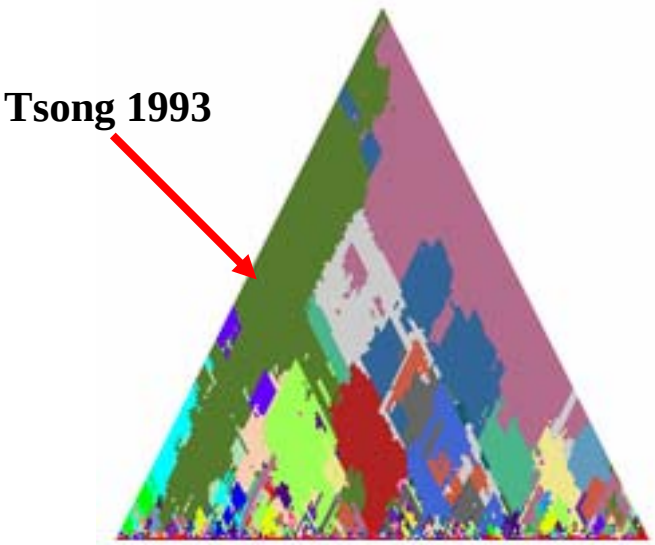
$1 : 2^{200}$

$1 : 10^{59}$

1 in $\sqrt{\text{googol}}$

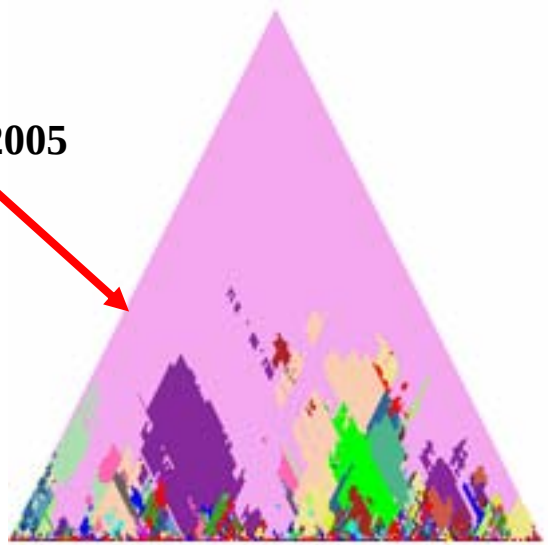
probability that same performer can produce a second performance so closely is equivalent to one atom out of an entire star.

Same Performer Over Time



Tsong 1993

23.7% Rubinstein 1952
22.8% Tsong 2005
9.0% Poblocka 1999
7.4% Olejniczac 1990
5.9% Clidat 1994
4.9% Fiorentino 1962
3.9% Rubinstein 1939
3.4% Uninsky 1971
2.8% Mohovich 1999
2.4% Jonas 1947
2.3% Francois 1956
1.8% Luisada 1990
1.7% Milkina 1970
1.6% Rubinstein 1966
1.0% Biret 1990



Tsong 2005

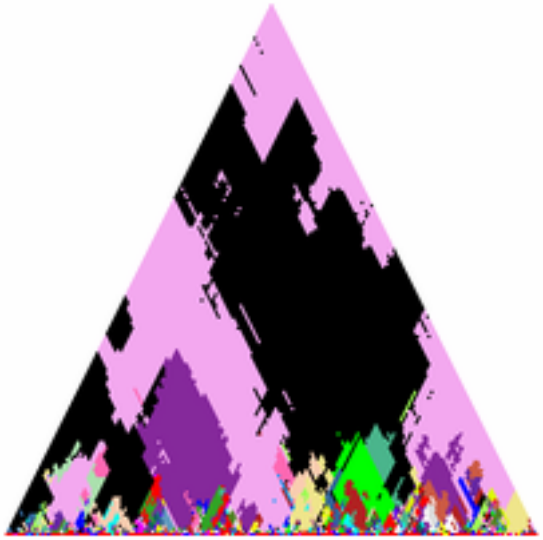
66.0% Tsong 1993
9.4% Shebanova 2002
6.5% Milkina 1970
2.7% Fliere 1977
2.0% Francois 1956
1.9% Indjic 2001
1.9% Rubinstein 1939
1.2% Fiorentino 1962
1.2% Poblocka 1999
1.1% Lushtak 2004

Mazurka in B minor 30/2

Including the Average

Tsong 1993

68.2% Average
4.9% Rubinstein 1952
3.7% Clidat 1994
3.2% Tsong 2005
3.1% Fiorentino 1962
2.8% Rubinstein 1939
2.2% Francois 1956
1.5% Rubinstein 1966
1.3% Uninsky 1971
1.2% Olejniczac 1990
1.1% Mohovich 1999
1.1% Jonas 1947

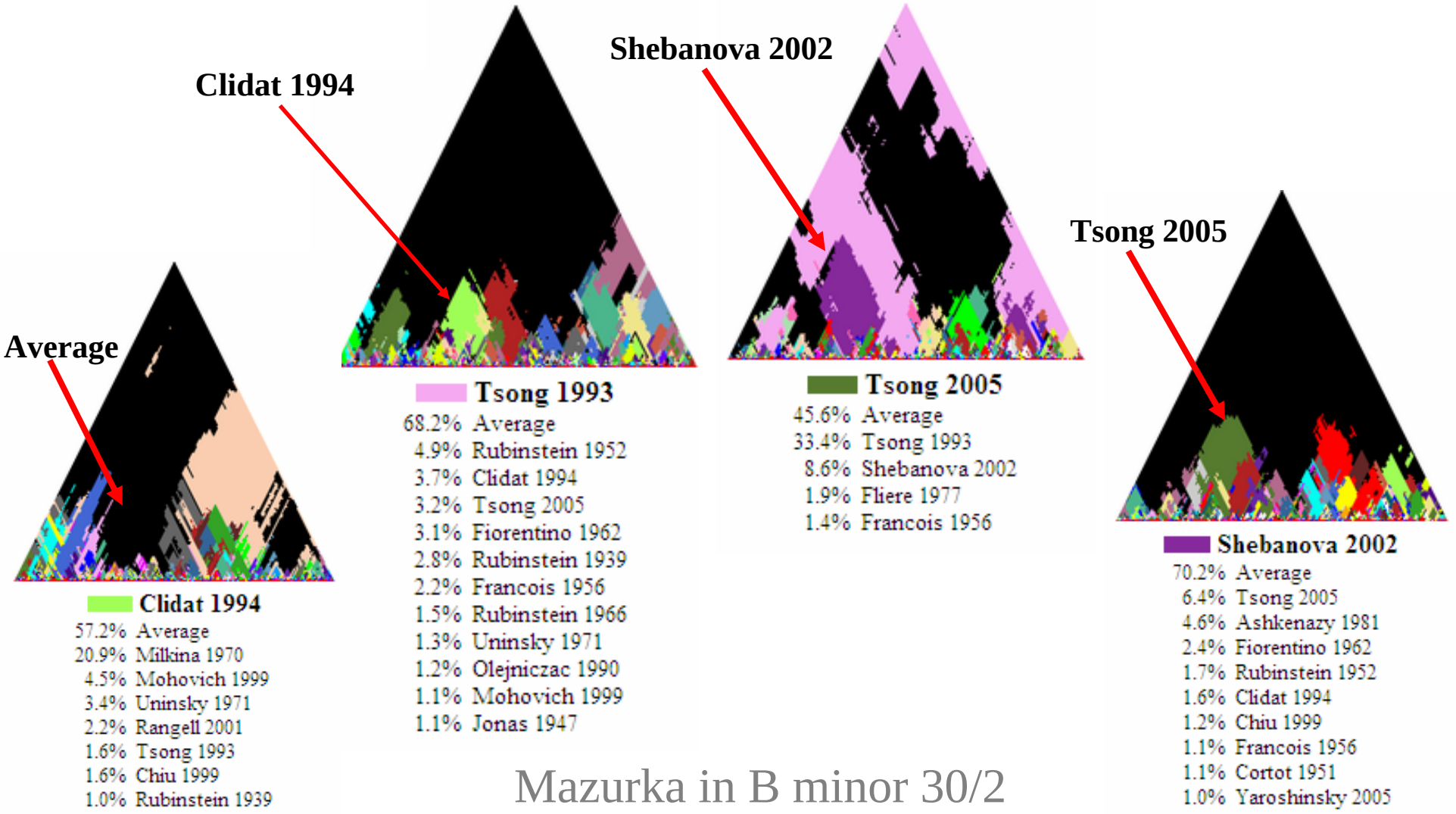


Tsong 2005

45.6% Average
33.4% Tsong 1993
8.6% Shebanova 2002
1.9% Fliere 1977
1.4% Francois 1956

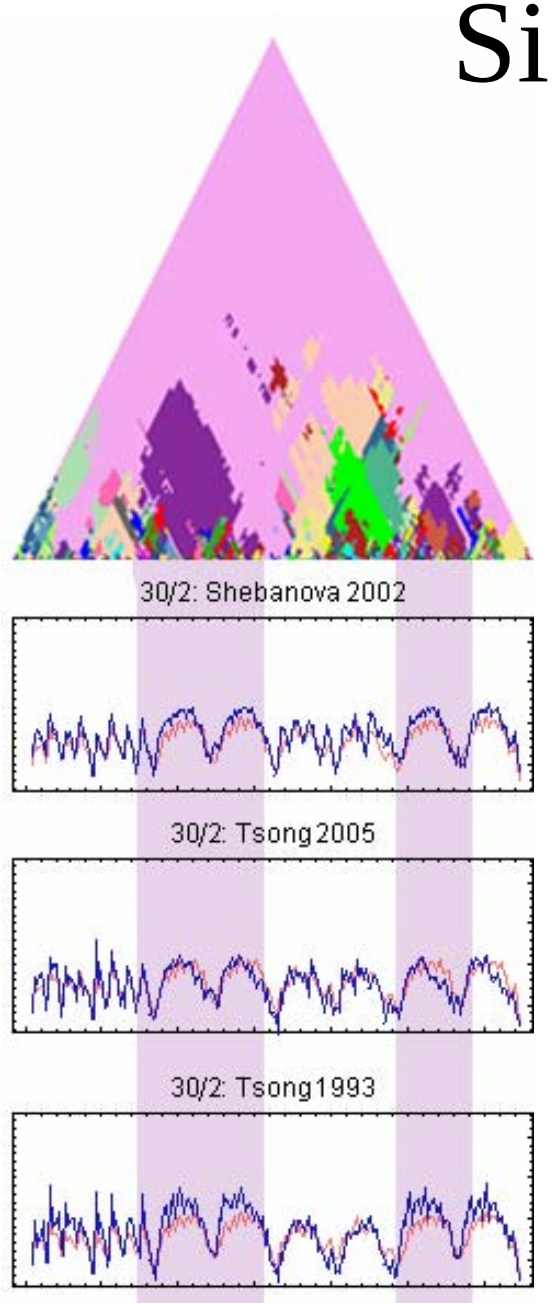
Mazurka in B minor 30/2

Mutual Best Matches



Mazurka in B minor 30/2

Significance of Similarity



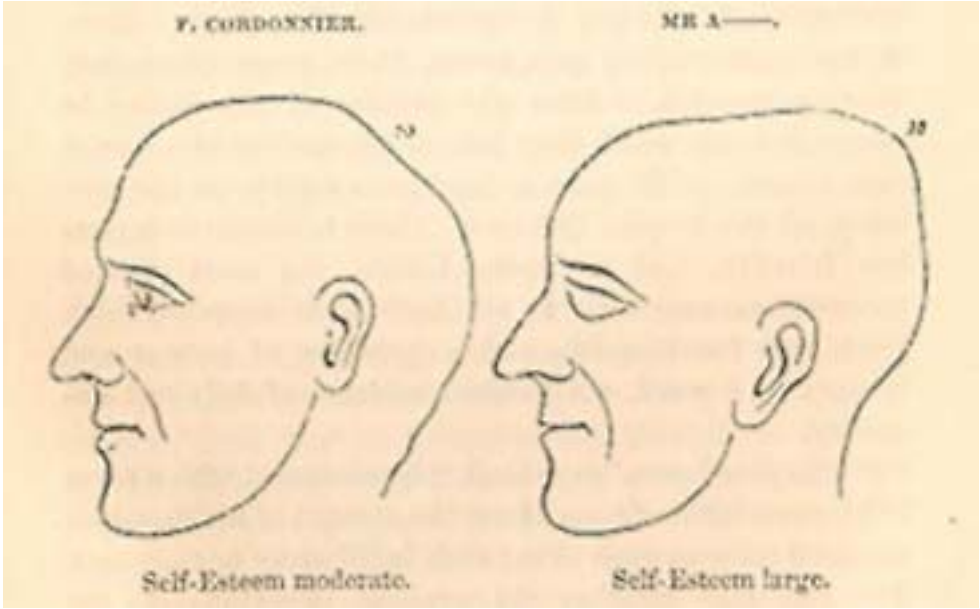
• Ts'ong 2005 performance matches best to Shebanova 2002 in 3 phrases when comparing 36 performances of mazurka 30/2.

• Is this a coincidence or not?

• Could ask the pianist (but might be problem in suggesting an answer beforehand). Also they might not remember or be totally conscious of the borrowing (such as accents in language). Or there could be a third performer between them.

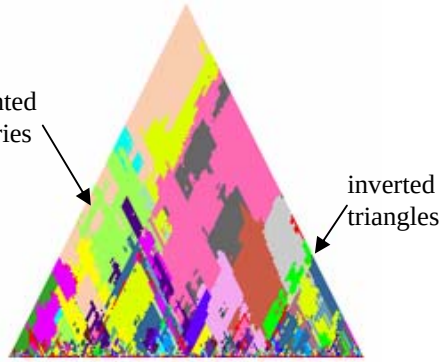
• Ideally a model would be used to calculate a probability of significance.

Phrenology



Significant or Not?

Example of non-significant matches (or at least very weak)

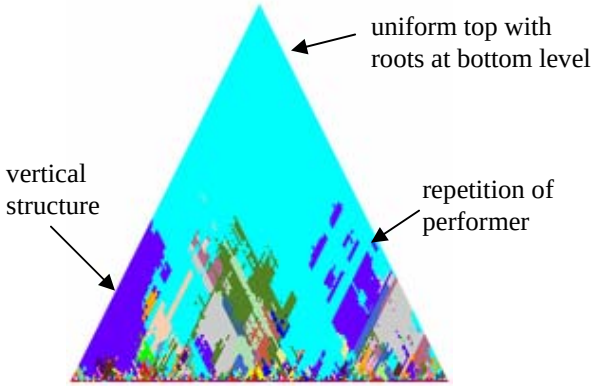


• foreground / background (bottom / top) don't match – no continuity in scope.

Uninsky 1971

20.0% Lushtak 2004
12.9% Milkina 1970
10.4% Hatto 1997
8.2% Clidat 1994
7.0% Mohovich 1999
6.1% Jonas 1947
4.5% Poblocka 1999
4.1% Ashkenazy 1982
3.9% Olejniczac 1990
3.8% Tsong 1993
3.7% Cortot 1951
2.9% Magaloff 1977
2.0% Fliere 1977
1.4% Biret 1990
1.3% Rangell 2001
1.2% Ashkenazy 1981
1.1% Rubinstein 1966

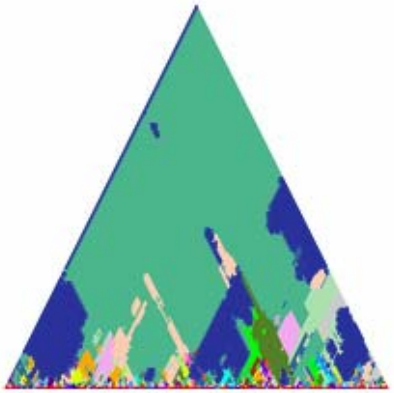
Example of possibly significant matches



Brailoswky 1960

60.1% Luisada 1990
13.2% Biret 1990
6.2% Olejniczac 1990
6.2% Smith 1975
2.4% Indjic 2001
1.8% Milkina 1970
1.7% Rubinstein 1952
1.3% Jonas 1947
1.3% Uninsky 1971

Match to same performer always significant



Rubinstein 1952

65.0% Rubinstein 1939
17.6% Rubinstein 1966
3.4% Milkina 1970
2.7% Indjic 2001
2.3% Smith 1975
1.7% Olejniczac 1990
1.5% Tsong 1993
1.2% Poblocka 1999

(Mazurka 30/2)

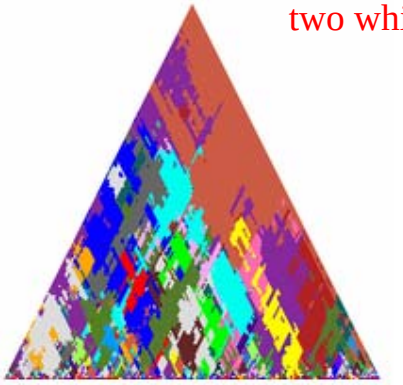
Purely Random Matching

- Plot has to show some match at all points…

Uninsky 1971

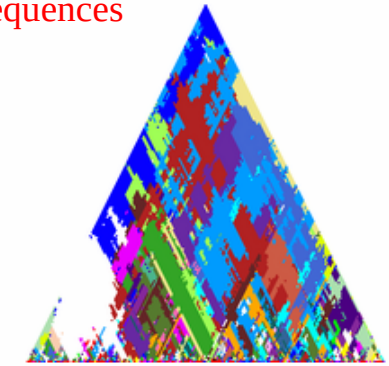
20.0% Lushtak 2004
12.9% Milkina 1970
10.4% Hatto 1997
8.2% Clidat 1994
7.0% Mohovich 1999
6.1% Jonas 1947
4.5% Poblocka 1999
4.1% Ashkenazy 1982
3.9% Olejniczac 1990
3.8% Tsong 1993
3.7% Cortot 1951
2.9% Magaloff 1977
2.0% Fliere 1977
1.4% Biret 1990
1.3% Rangell 2001
1.2% Ashkenazy 1981
1.1% Rubinstein 1966

two white-noise sequences



Random1

22.7% Jonas 1947
14.1% Shebanova 2002
8.3% Blet 2003
8.0% Chiu 1999
7.3% Random2
6.0% Tsong 2005
4.8% Mohovich 1999
4.4% Fiorentino 1962
3.3% Cortot 1951
2.5% Fliere 1977
2.4% Lushtak 2004
2.1% Michelangeli 1971
2.1% Smith 1975
2.1% Sofronitsky 1960
1.7% Tsong 1993
1.6% Ferenczy 1956
1.4% Ashkenazy 1981



Random2

17.7% Brailoswky 1960
13.8% Fiorentino 1962
10.1% Random1
7.6% Blet 2003
7.1% Uninsky 1971
6.9% Yaroshinsky 2005
4.8% Rangell 2001
3.8% Sofronitsky 1960
3.7% Clidat 1994
3.1% Francois 1956
3.0% Jonas 1947
2.8% Tsong 2005
2.2% Magaloff 1977
1.9% Ferenczy 1956
1.8% Ashkenazy 1982
1.6% Luisada 1990
1.5% Indjic 2001
1.2% Shebanova 2002

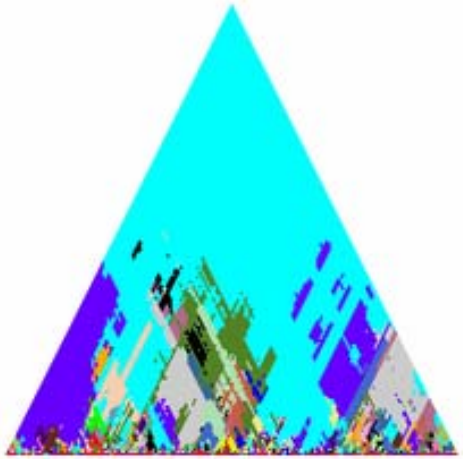
- Many performances are equidistant to Uninsky performance

Including Average Performance

helps but does not solve significance question

Uninsky 1971

57.4% Average
7.6% Lushtak 2004
4.0% Jonas 1947
4.0% Ashkenazy 1982
2.9% Olejniczac 1990
2.6% Cortot 1951
2.5% Tsong 1993
2.3% Clidat 1994
1.9% Milkina 1970
1.9% Poblocka 1999
1.7% Hatto 1997
1.7% Magaloff 1977
1.3% Mohovich 1999
1.3% Rangell 2001
1.2% Biret 1990
1.1% Fliere 1977



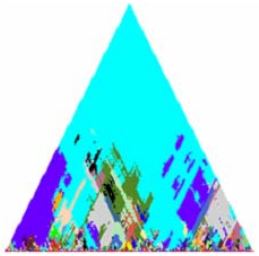
Brailoswky 1960

59.8% Luisada 1990
13.2% Biret 1990
6.2% Olejniczac 1990
5.8% Smith 1975
2.3% Indjic 2001
1.6% Milkina 1970
1.5% Rubinstein 1952
1.4% Average
1.3% Jonas 1947
1.3% Uninsky 1971

Rubinstein 1952

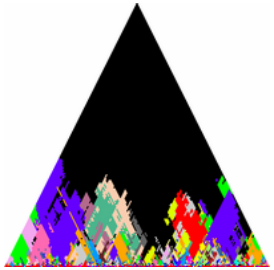
48.5% Rubinstein 1939
27.8% Average
13.0% Rubinstein 1966
1.9% Smith 1975
1.3% Tsong 1993
1.2% Milkina 1970
1.1% Indjic 2001
1.1% Olejniczac 1990

(mazurka 30/2)



Brailowsky

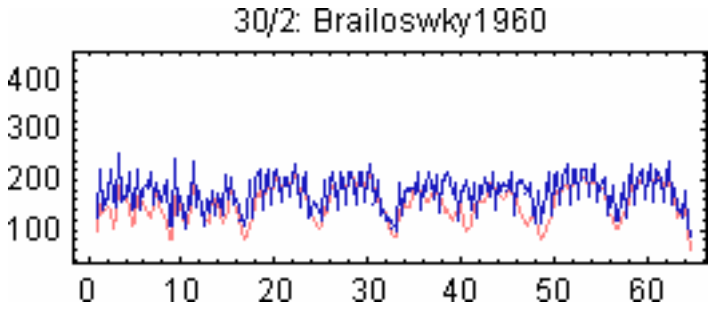
What Is Significant?

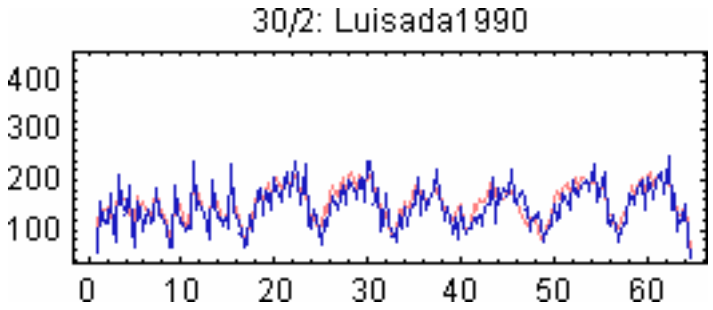


Luisada

- No direct link found on web between Brailowsky and Luisada (such as teacher/student).

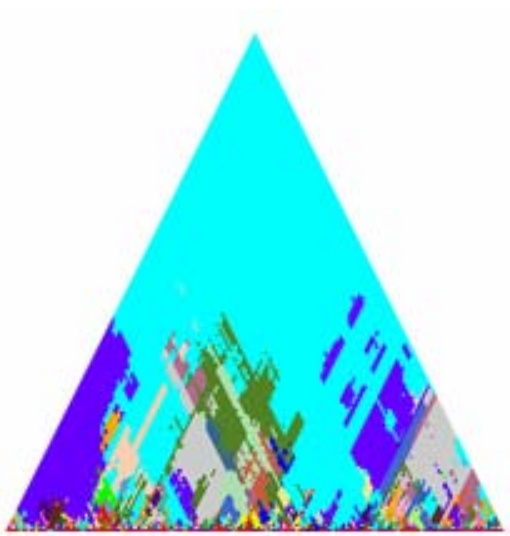
- Strong match in Brailowsky to Luisada probably due to large amount of mazurka metric pattern:





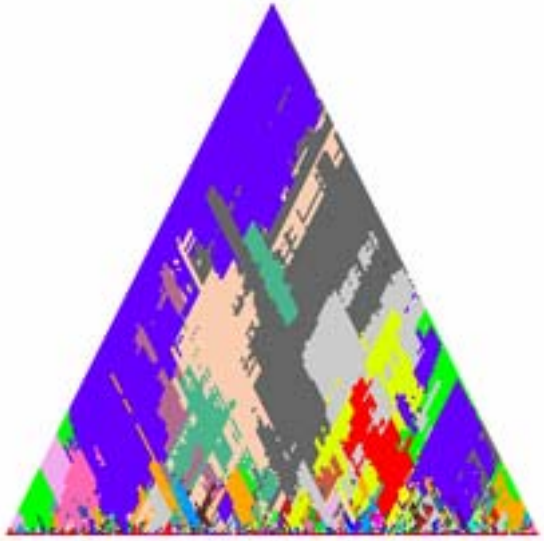
- Phrasing shapes very different, so match is both significant (high frequencies match) and not significant (low frequencies don’t match).

Best Matching Not Mutual



Brailoswky 1960

60.1% Luisada 1990
13.2% Biret 1990
6.2% Olejniczac 1990
6.2% Smith 1975
2.4% Indjic 2001
1.8% Milkina 1970
1.7% Rubinstein 1952
1.3% Jonas 1947
1.3% Uninsky 1971



Luisada 1990

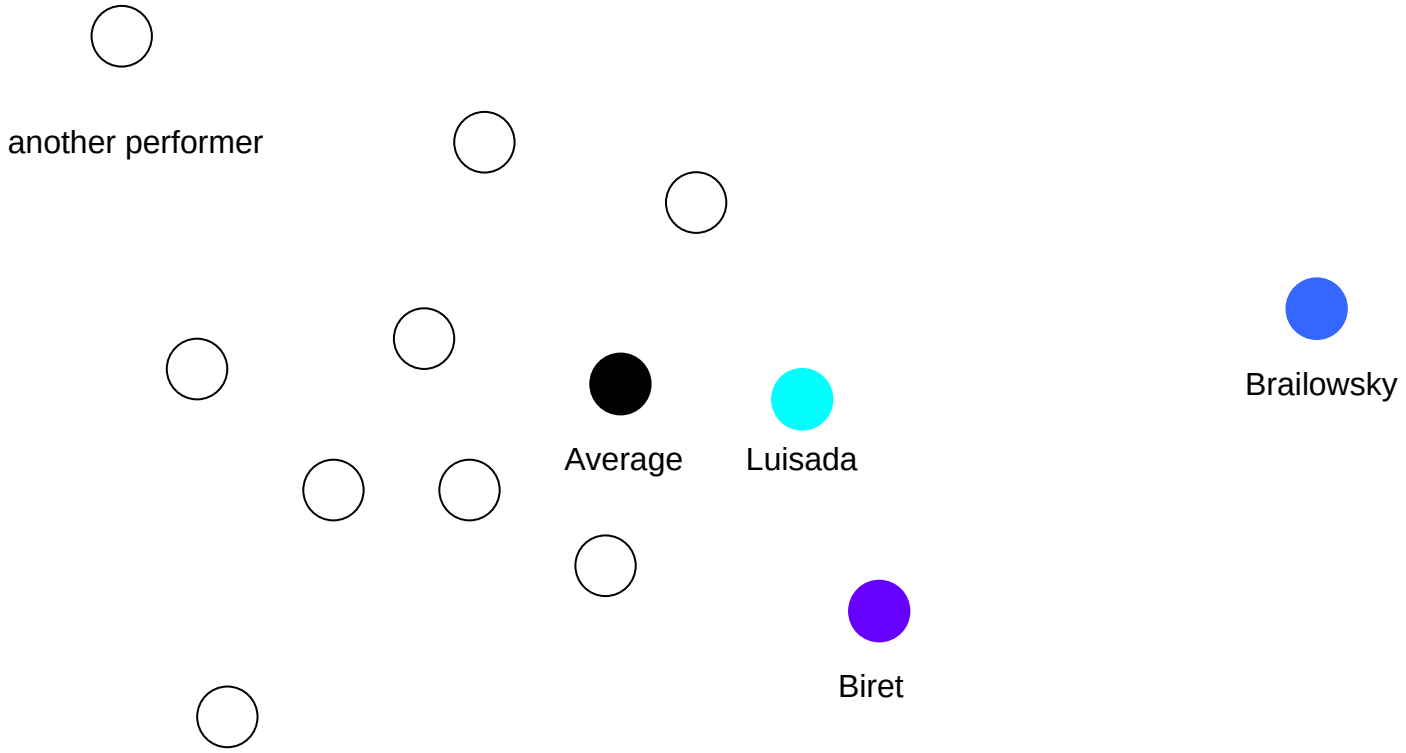
32.2% Biret 1990
20.3% Mohovich 1999
10.4% Milkina 1970
9.0% Olejniczac 1990
5.2% Rubinstein 1939
4.0% Hatto 1997
3.6% Fliere 1977
3.1% Ashkenazy 1981
2.8% Ferenczy 1956
2.6% Rubinstein 1952
1.6% Lushtak 2004
1.1% Tsong 1993

?

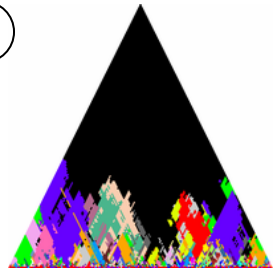
- Looking at both performers pictures helps with “significance”

Performance Map Schematic

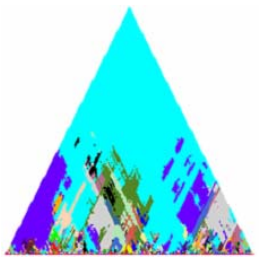
- Brailowsky has the strongest mazurka meter pattern
- Luisada has the second strongest mazurka meter pattern



Luisada:

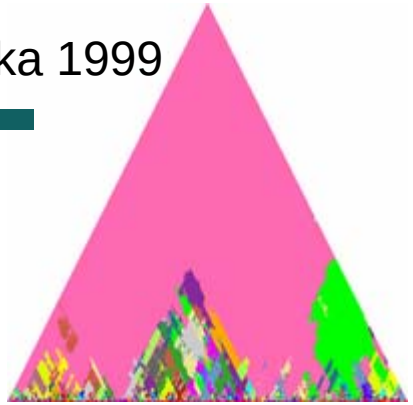


Brailowsky:

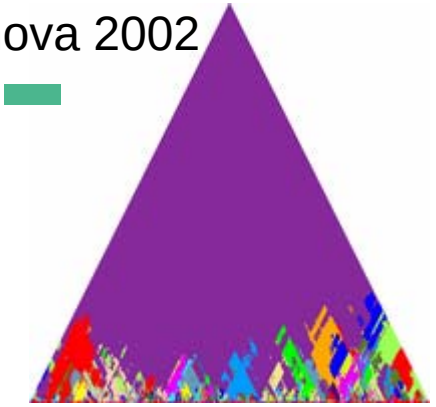


Strong Interpretive Influences

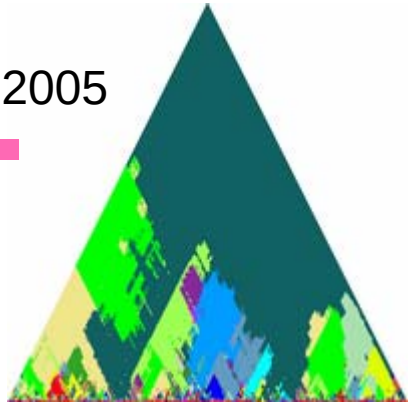
Poblocka 1999



Shebanova 2002

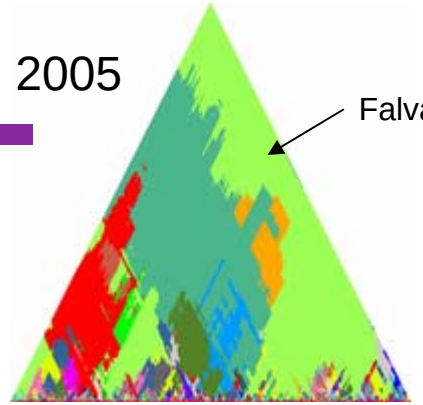


Nezu 2005



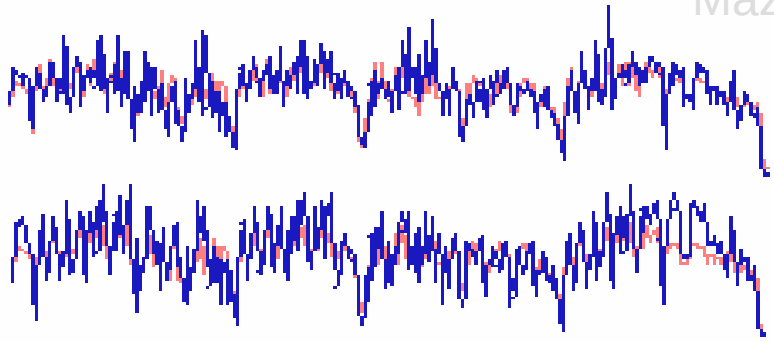
Tsujii 2005

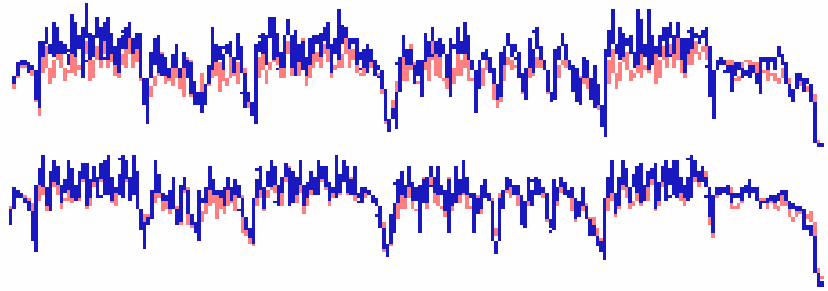
Falvay 1989



Mazurka in C Major 24/2

• note parallel colors





Performance Ranking

- Given a reference performance,

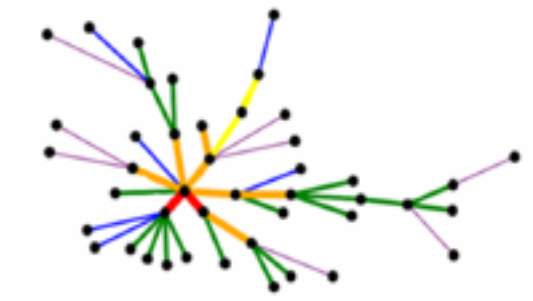
  -- which other performance matches best
  -- which other performance matches second best
  …
  -- which other performance matches worst

0^{th}-Order Similarity Rank

- Use large-scale correlation to order performances similarity to a target

performance	rank	correlation	
Rubinstein 1952	0	1.00	← target
Average	1	0.905	← best match
Rubinstein 1966	2	0.899	
Milkina 1970	3	0.876	
Poblocka 1999	4	0.836	
Tsong 1993	5	0.814	
Biret 1990	6	0.807	
Mohovich 1999	7	0.805	
Hatto 1997	8	0.799	
Indjic 2001	9	0.798	
Rubinstein 1939	10	0.784	
Shebanova 2002	11	0.783	
Luisada 1990	12	0.767	
Magaloff 1977	13	0.751	
Olejniczac 1990	14	0.740	
Blet 2003	15	0.721	
Clidat 1994	16	0.716	
Rangell 2001	17	0.716	
Lushtak 2004	18	0.715	
Chiu 1999	19	0.709	
Tsong 2005	20	0.706	
Smith 1975	21	0.695	
Fliere 1977	22	0.678	
Brailoswky 1960	23	0.644	
Ashkenazy 1982	24	0.642	
Ashkenazy 1981	25	0.637	
Cortot 1951	26	0.633	
Ferenczy 1956	27	0.628	
Fiorentino 1962	28	0.615	
Uninsky 1971	29	0.597	
Francois 1956	30	0.577	
Yaroshinsky 2005	31	0.565	
Sofronitsky 1960	32	0.552	
Michelangeli 1971	33	0.550	
Jonas 1947	34	0.415	← worst match
Random1	35	0.102	} synthetic noise
Random2	36	0.054	
Random3	37	-0.015	

- Performance maps used rank #1 data:



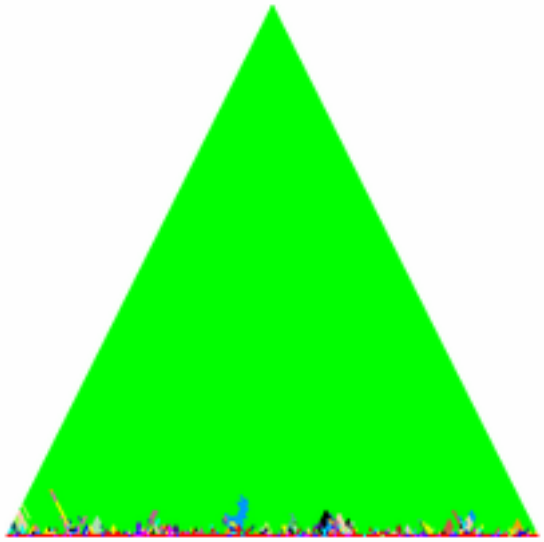
1st-Order Scape Rank

Smith 1975

56.9% Shebanova 2002
11.0% Fliere 1977
10.0% Average
4.7% Magaloff 1978
2.5% Brailowsky 1960
2.3% Tsong 1993
2.1% Ashkenazy 1981
1.9% Jonas 1947
1.6% Chiu 1999
1.4% Biret 1990

(mazurka 68/3)

- Area represented by best choice in scape plot.
- Hatto effect causes problems:

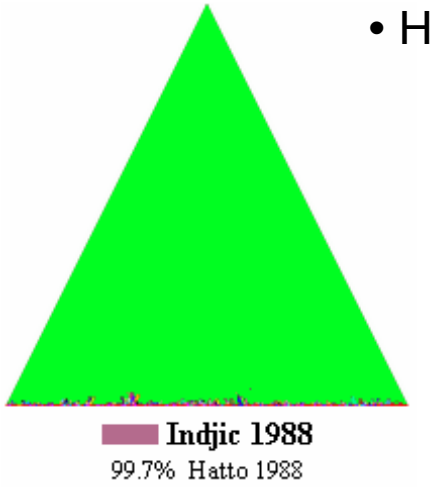


Indjic 2001

98.4% Hatto 1997

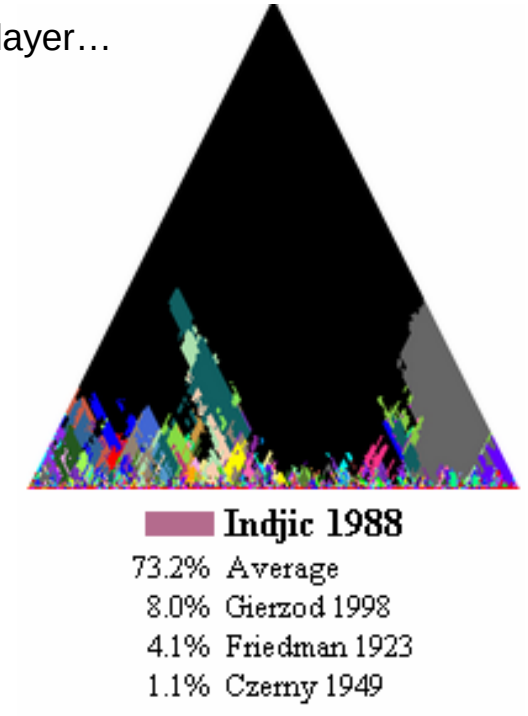
- Who is #2 for Indjic?

Scape Layers

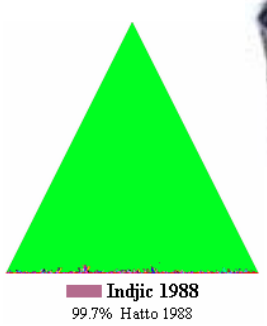


- Hatto takes up nearly 100% of Indjic's scape

- So remove Hatto layer…

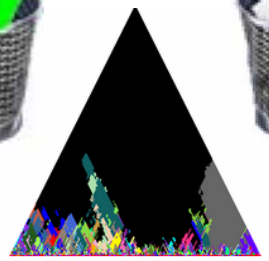


Peeling the Layers



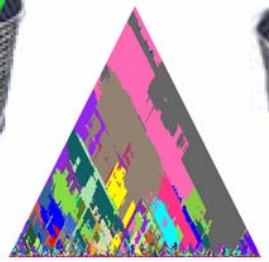
Indjic 1988
99.7% Hatto 1988

remove Hatto



Indjic 1988
73.2% Average
8.0% Gierzod 1998
4.1% Friedman 1923
1.1% Czerny 1949

remove Average

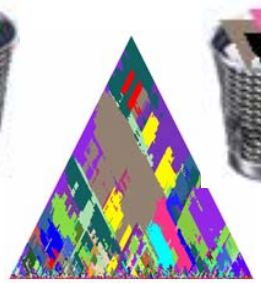


Indjic 1988
19.3% Gierzod 1998
19.2% Uninsky 1971
16.1% Fliere 1977
6.5% Friedman 1923
4.4% Osinska 1989
3.8% Rubinstein 1966
3.3% Poblocka 1999
2.6% Czerny 1949
2.6% Boshniakovich 1969
2.4% Biret 1990
2.2% Ferenczy 1958
1.9% Smith 1975
1.8% Harasiewicz 1955
1.2% Rachmaninoff 1923
1.1% Magaloff 1978
1.1% Shebanova 2002

remove Gierzod

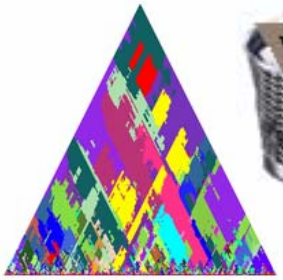
Indjic 1988
26.6% Fliere 1977
19.3% Uninsky 1971
9.1% Osinska 1989
6.9% Friedman 1923
4.7% Rubinstein 1966
3.3% Poblocka 1999
2.9% Czerny 1949
2.6% Boshniakovich 1969
2.4% Biret 1990
2.4% Smith 1975
2.2% Ferenczy 1958
1.8% Harasiewicz 1955
1.3% Milkina 1970
1.3% Rachmaninoff 1923
1.1% Magaloff 1978
1.1% Shebanova 2002

remove Fliere



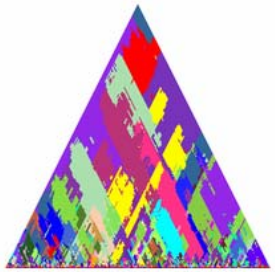
Indjic 1988
21.9% Uninsky 1971
13.5% Friedman 1923
10.1% Osinska 1989
6.9% Schilhawsky 1960
5.6% Boshniakovich 1969
4.8% Rubinstein 1966
4.1% Czerny 1949
3.4% Poblocka 1999
3.4% Harasiewicz 1955
3.0% Smith 1975
2.4% Biret 1990
2.4% Ferenczy 1958
1.5% Afanassiev 2001
1.4% Rachmaninoff 1923
1.3% Milkina 1970
1.1% Magaloff 1978
1.1% Zak 1937
1.1% Shebanova 2002

remove Uninsky



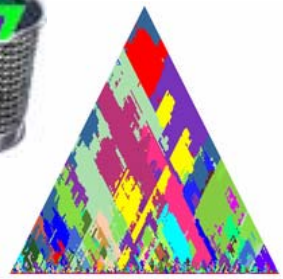
Indjic 1988
13.8% Friedman 1923
12.6% Osinska 1989
10.4% Shebanova 2002
7.7% Schilhawsky 1960
7.6% Boshniakovich 1969
6.8% Czerny 1949
5.4% Poblocka 1999
4.8% Rubinstein 1966
3.4% Harasiewicz 1955
3.0% Smith 1975
2.8% Ferenczy 1958
2.5% Biret 1990
2.2% Afanassiev 2001
1.5% Milkina 1970
1.4% Rachmaninoff 1923
1.3% Kissin 1993
1.2% Magaloff 1978
1.1% Zak 1937
1.0% Neighaus 1950

remove Friedman



Indjic 1988
13.9% Osinska 1989
11.1% Czerny 1949
10.4% Shebanova 2002
8.7% Schilhawsky 1960
7.6% Boshniakovich 1969
5.5% Poblocka 1999
5.0% Rubinstein 1966
4.8% Harasiewicz 1955
4.6% Afanassiev 2001
3.3% Smith 1975
2.8% Ferenczy 1958
2.5% Biret 1990
1.9% Rachmaninoff 1923
1.7% Neighaus 1950
1.6% Friedman 1930
1.5% Milkina 1970
1.5% Zak 1937
1.3% Kissin 1993
1.3% Magaloff 1978

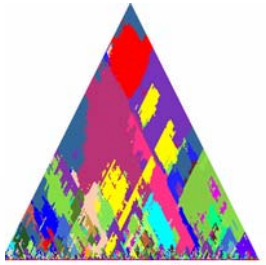
remove Osinksa



Indjic 1988
13.4% Czerny 1949
12.6% Shebanova 2002
8.7% Schilhawsky 1960
7.7% Boshniakovich 1969
7.0% Harasiewicz 1955
6.4% Smith 1975

remove Czerny-Stefanska

5.7% Rubinstein 1966
5.6% Poblocka 1999
5.1% Afanassiev 2001
2.9% Ferenczy 1958
2.5% Biret 1990
2.0% Rachmaninoff 1923
1.8% Neighaus 1950
1.7% Friedman 1930
1.6% Zak 1937
1.5% Milkina 1970
1.4% Kissin 1993
1.4% Rosen 1989
1.3% Magaloff 1978
1.0% Wasowski 1980
1.0% Falvay 1989



Indjic 1988
16.9% Shebanova 2002
9.9% Schilhawsky 1960
9.6% Harasiewicz 1955
8.2% Boshniakovich 1969
6.6% Afanassiev 2001
6.4% Smith 1975
6.0% Rubinstein 1966

5.6% Poblocka 1999
2.9% Ferenczy 1958
2.8% Friedman 1930
2.6% Biret 1990
2.4% Rachmaninoff 1923
2.2% Neighaus 1950
1.8% Magaloff 1978
1.8% Zak 1937
1.6% Milkina 1970
1.4% Rosen 1989
1.4% Kissin 1993
1.0% Wasowski 1980
1.0% Falvay 1989

2nd-Order Scape Rank

- Rank score = area represented by best choice in scape plot, but peel away previous best choices.

performance	0-rank		1-rank		2-rank	
Indjic 2001	0	1.000	0	1.000	0	1.000
Hatto 1997	1	0.989	1	0.989	1	0.963
Average	2	0.861	2	0.00174	2	0.708
Poblocka 1999	4	0.796	3	0.00168	3	0.246
Rubinstein 1952	3	0.798	18	0.000225	4	0.156
Milkina 1970	5	0.791	30	0	5	0.188
Rubinstein 1939	12	0.714	13	0.000281	6	0.186
Mohovich 1999	6	0.784	17	0.000225	7	0.130
Luisada 1990	7	0.769	27	0	8	0.140
Biret 1990	8	0.763	4	0.00118	9	0.211
Rubinstein 1966	9	0.758	21	0.0000563	10	0.145
Olejniczac 1990	11	0.720	9	0.000394	11	0.137
Ashkenazy 1982	26	0.633	23	0	12	0.114
Ashkenazy 1981	27	0.628	5	0.000901	13	0.188
Francois 1956	10	0.721	7	0.000619	14	0.119
Uninsky 1971	17	0.697	20	0.000225	15	0.149
Fliere 1977	24	0.646	26	0	16	0.118
Smith 1975	28	0.627	22	0.0000562	17	0.092
Clidat 1994	18	0.677	6	0.000788	18	0.087
Tsong 1993	14	0.706	14	0.000281	19	0.076
Shebanova 2002	13	0.707	32	0	20	0.058
Blet 2003	15	0.706	24	0	21	0.064
Lushtak 2004	19	0.676	16	0.000225	22	0.066
Chiu 1999	20	0.672	12	0.000281	23	0.060
Magaloff 1977	16	0.698	28	0	24	0.077
Tsong 2005	21	0.659	33	0	25	0.070
Brailoswky 1960	23	0.649	10	0.000338	26	0.081
Ferenczy 1956	22	0.654	8	0.000506	27	0.084
Rangell 2001	25	0.635	31	0	28	0.108
Sofronitsky 1960	33	0.379	19	0.000225	29	0.054
Cortot 1951	29	0.605	25	0	30	0.067
Fiorentino 1962	31	0.567	11	0.000338	31	0.062
Yaroshinsky 2005	30	0.575	34	0	32	0.079
Michelangeli 1971	32	0.506	29	0	33	0.082
Jonas 1947	34	0.307	15	0.000225	34	0.101
Random2	36	0.034	36	0	35	0.044
Random1	35	0.049	35	0	36	0.044
Random3	37	-0.088	37	0	37	0.026

- Still slightly sensitive to the Hatto effect

3rd-Order Scape Rank

• Start with the 2nd-order rankings, selecting a cutoff point in the rankings to define a background noise level in the scape.

• Then one-by-one add each of the non-noise performances into the scape along with the background noise performances. Measure the area covered by the non-noise performance (only one non-noise performance at a time).

3rd-Order Rankings

Rubinstein 1952	0	1.000	0	1.000
Average	1	0.904	1	0.933
Rubinstein 1939	10	0.784	2	0.862
Rubinstein 1966	2	0.899	3	0.849
Milkina 1970	3	0.875	4	0.831
Poblocka 1999	4	0.835	5	0.700
Mohovich 1999	7	0.805	6	0.664
Tsong 1993	5	0.814	7	0.636
Biret 1990	6	0.806	8	0.622
Indjic 2001	9	0.797	9	0.621
Hatto 1997	8	0.798	10	0.616
Olejniczac 1990	14	0.739	11	0.541
Shebanova 2002	11	0.782	12	0.509
Luisada 1990	12	0.766	13	0.426
Magaloff 1977	13	0.750	14	0.338
Lushtak 2004	18	0.715	15	0.277
Tsong 2005	20	0.705	16	0.217
Blet 2003	15	0.720	17	0.195
Ferenczy 1956	27	0.627	18	0.169
Ashkenazy 1981	25	0.637	19	0.133
Fliere 1977	22	0.677	20	0.127
Fiorentino 1962	28	0.615	21	0.116
Clidat 1994	16	0.716	22	0.104
Smith 1975	21	0.694	23	0.101
Rangell 2001	17	0.715	24	0.100
Ashkenazy 1982	24	0.641	25	0.094
Chiu 1999	19	0.708	26	0.094
Yaroshinsky 2005	31	0.564	27	0.094
Cortot 1951	26	0.633	28	0.088
Brailoswky 1960	23	0.643	29	0.073
Uninsky 1971	29	0.596	30	0.072
Michelangeli 1971	33	0.550	31	0.071
Sofronitsky 1960	32	0.552	32	0.070
Francois 1956	30	0.577	33	0.069
Jonas 1947	34	0.415	34	0.066
Random1	35	0.102	35	0.046
Random2	36	0.054	36	0.046
Random3	37	-0.015	37	0.026

target

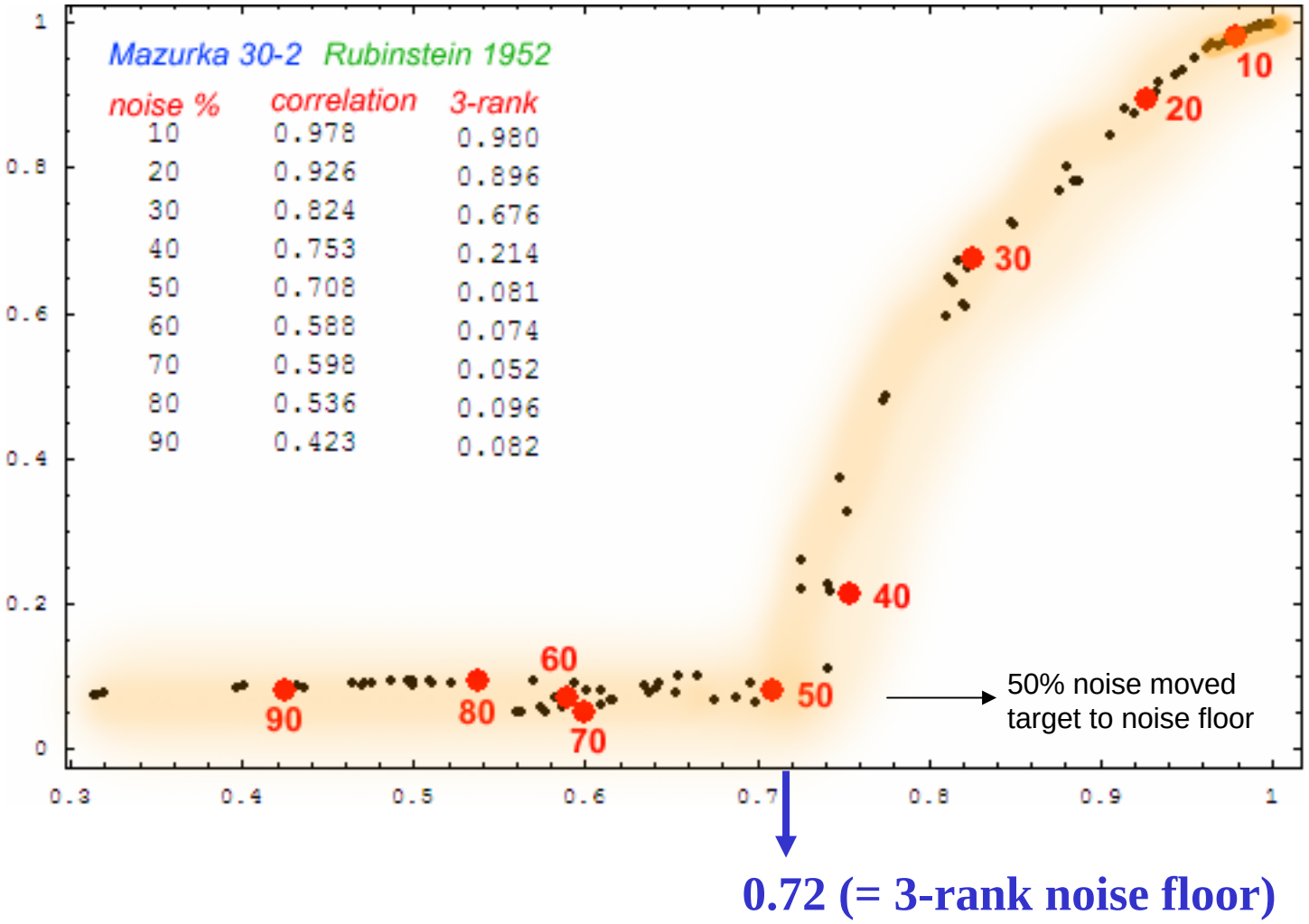
same performer

50% noise floor

(2-rankings below "noise floor")

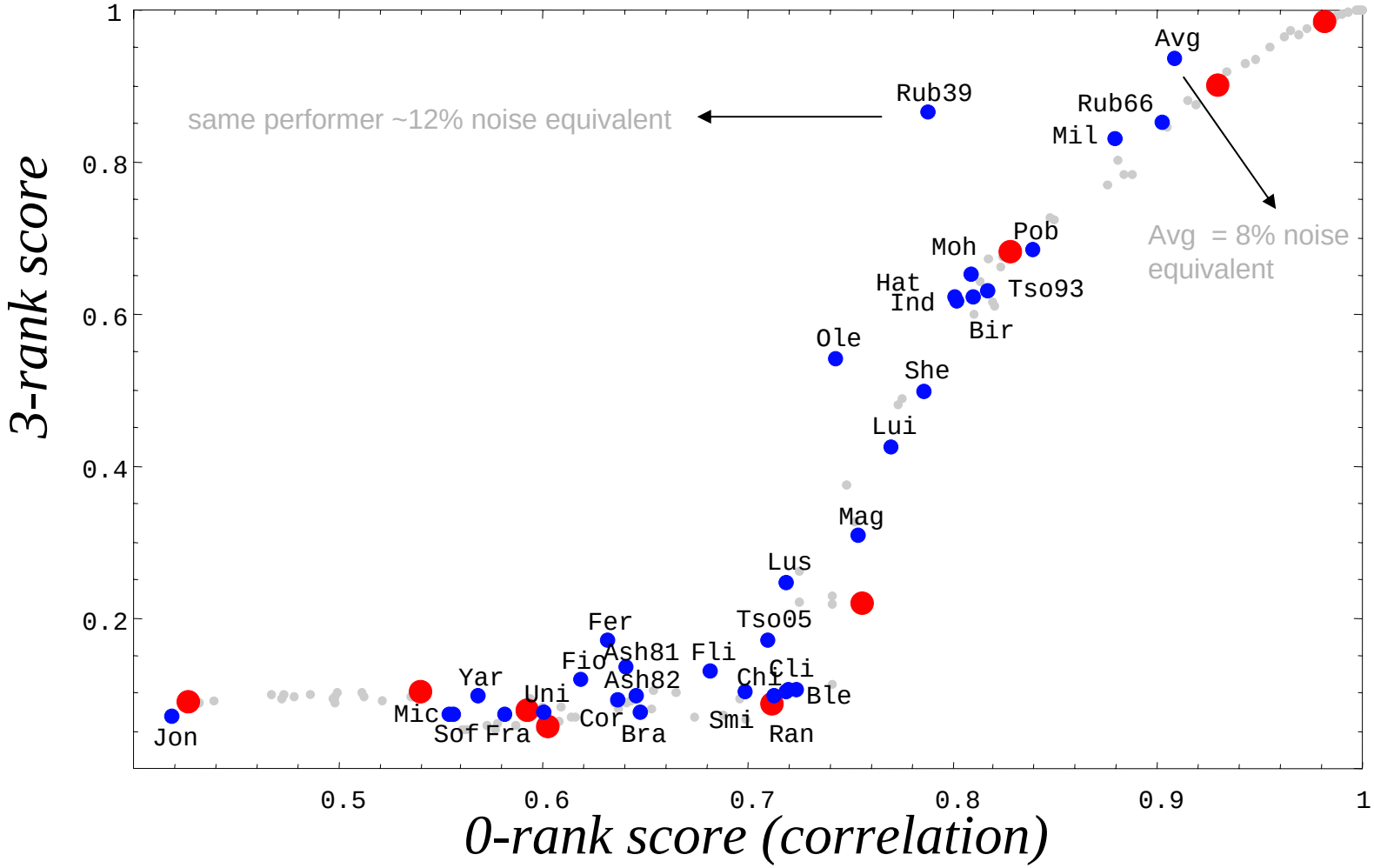
Proportional Noise

- Gradually add noise to target



Real Data (1)

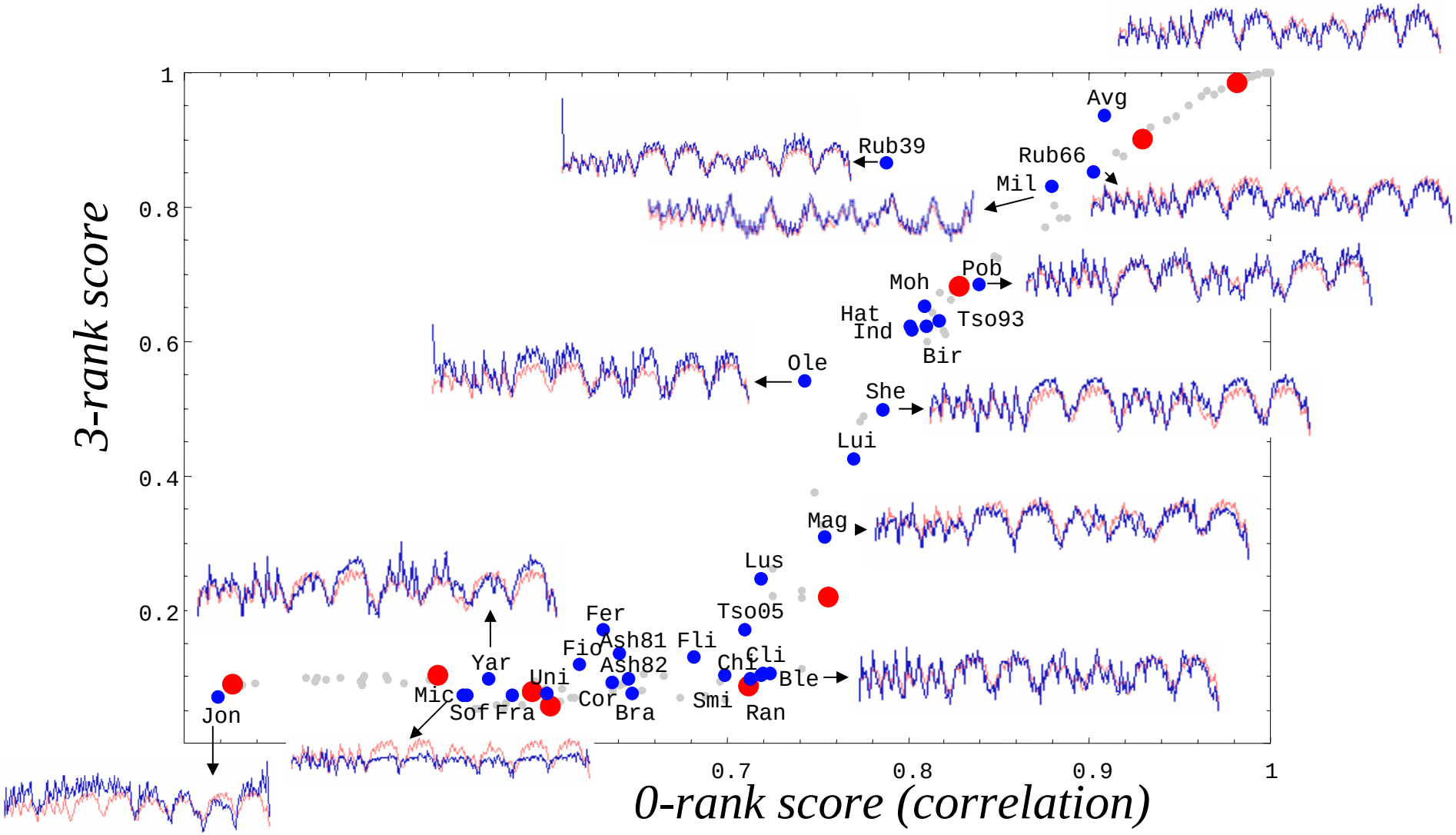
Mazurka 30/2
Target: Rubinstein 1952



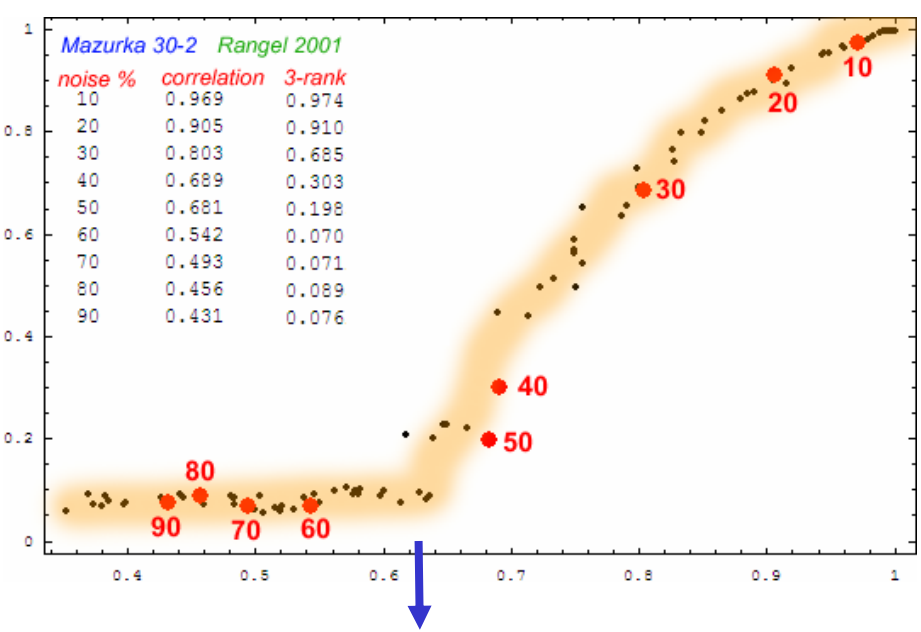
Real Data (2)

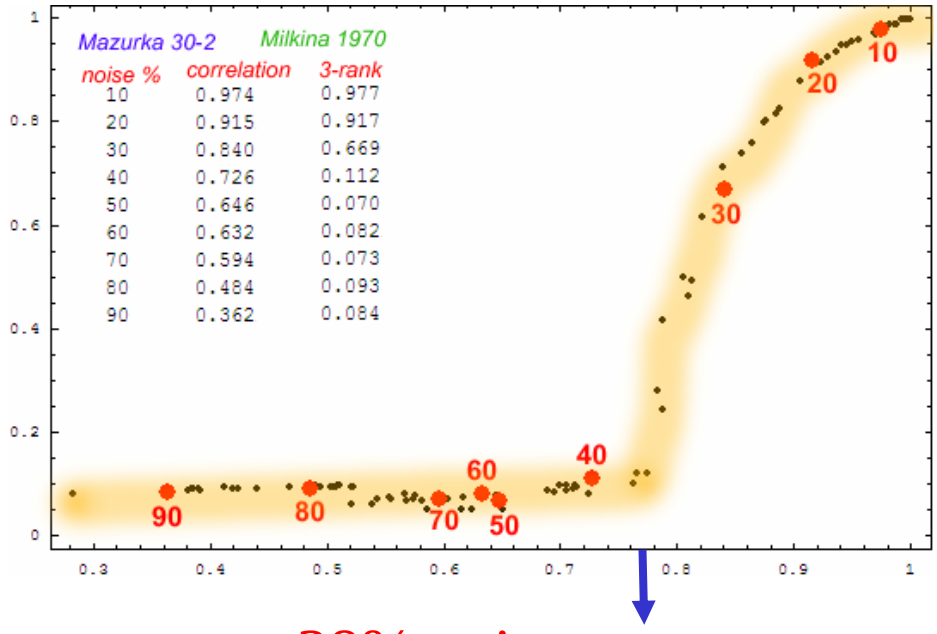
Mazurka 30/2

Target: Rubinstein 1952



Distance to the Noise Floor





0.62 , 55% noise

38% noise, **0.77**

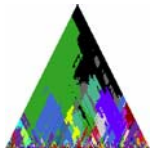
- Metric for measuring individuality of interpretation?

- 3-Rank scores more absolute than correlation values
  - noise floor is always about a 3-rank score of 10%
- 3-Rank scores less sensitive to local extrema

Cortot Performance Ranking

- Master class recording contains 48 out of 64 measures (75%)

Con. Artists Rankings



0-Rank:

1. Average
2. Rangell 01
3. Milkina 70
4. Mohovich 99
5. Shebanova 02

…

32. Masterclass

3-Rank

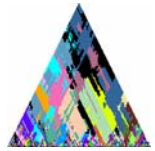
1. Average
2. Rangell 01
3. Mohovich 99
4. Rubinstein 39
5. Milkina 70

…

31. Masterclass

Match to other Cortot
near bottom of rankings.

Masterclass Rankings



0-Rank:

1. Poblocka 99
2. Average
3. Rubinstein 52
4. Tsong 93
5. Tsong 05

…

33. Con. Artist

3-Rank

1. Average
2. Rubinstein 52
3. Luisada 90
4. Poblocka 99
5. Hatto 94

…

35. Con. Artist

Match to other Cortot
near bottom of rankings.

(comparing 35 performances + average)