Computational Performance Analysis

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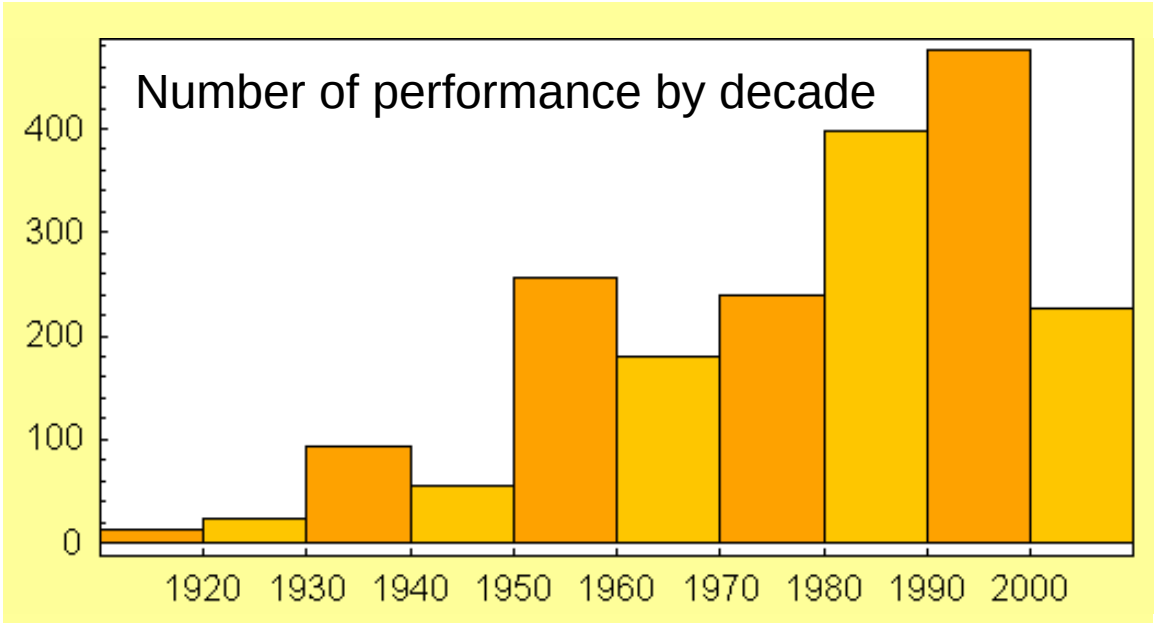
CHARM

25 April 2007
CCRMA Colloquium

Mazurka Project

- **2,076 recordings of 49 mazurkas**
  = 42 performances/mazurka on average
  ***least*: 30 performances of 41/1**
  ***most*: 60 performances of 63/3**

- **99 performers on 150 CDs, 93 hours of music**
- **Earliest is 1907 Pachmann performance of 50/2**



Performers of mazurka 63/3:

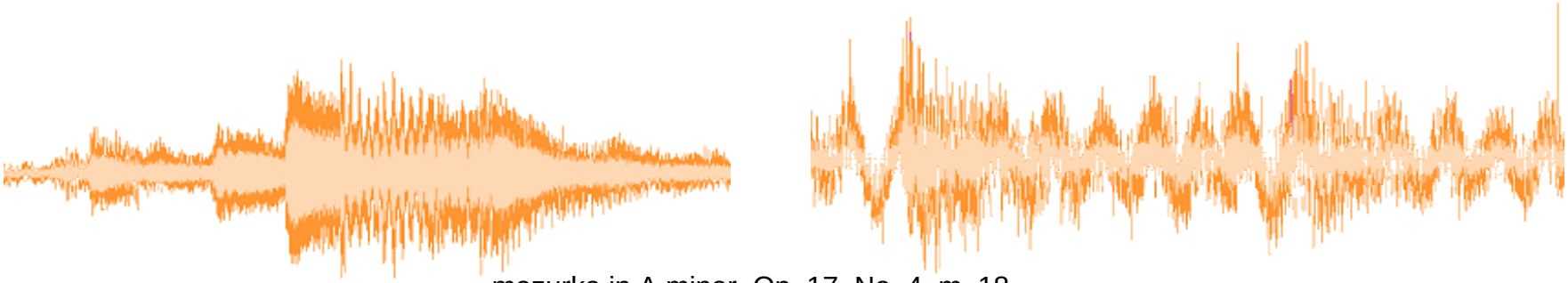
Afanassiev (2001)
Anderszewski (2003)
Ashkenazy (1981)
Biret (1990)
Blet (2003)
Block (1995)
Blumental (1952)
Boshniakovich (1969)
Brailowsky (1960)
Bunin (1987)
Chiu (1999)
Cohen (1997)
Cortot (1951)
Czerny-Stefańska (1949)
Ezaki (2006)
Falvay (1989)
Ferenczy (1958)
Flière (1977)
François (1956)
Friedman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

see mazurka.org.uk/info/discography

1. Data Extraction:

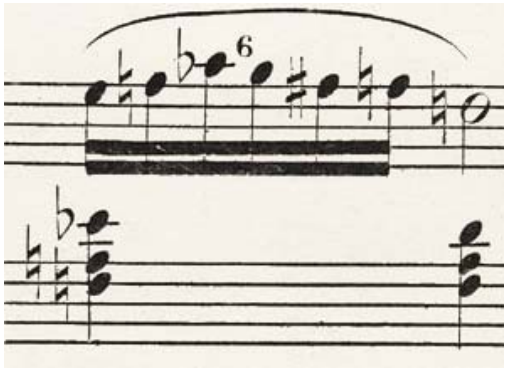
- Beat durations/tempo
- Beat loudnesses

Reverse conducting

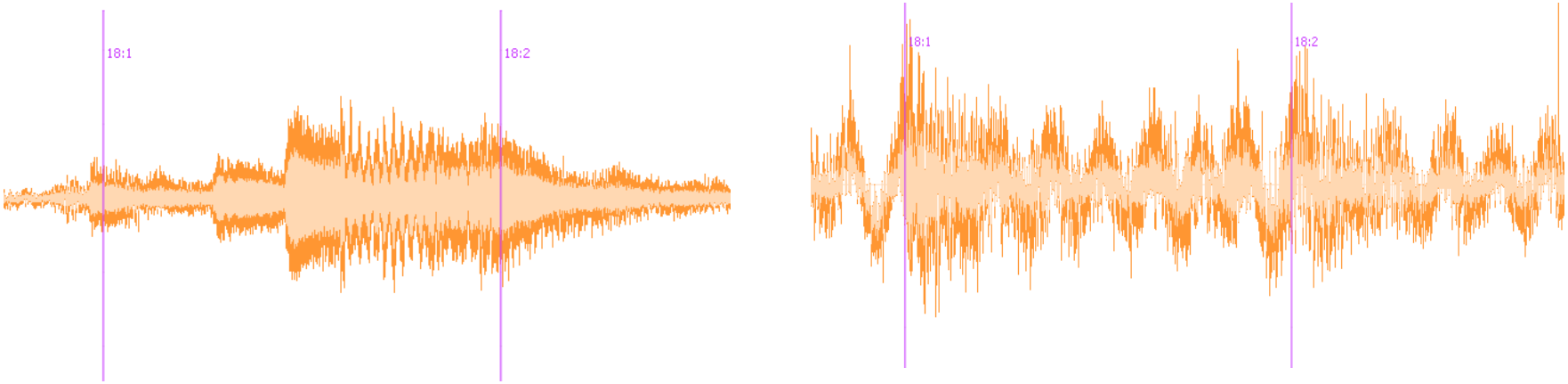


mazurka in A minor, Op. 17, No. 4, m. 18

Frederic Chiu, 1999



Édouard Risler, 1920

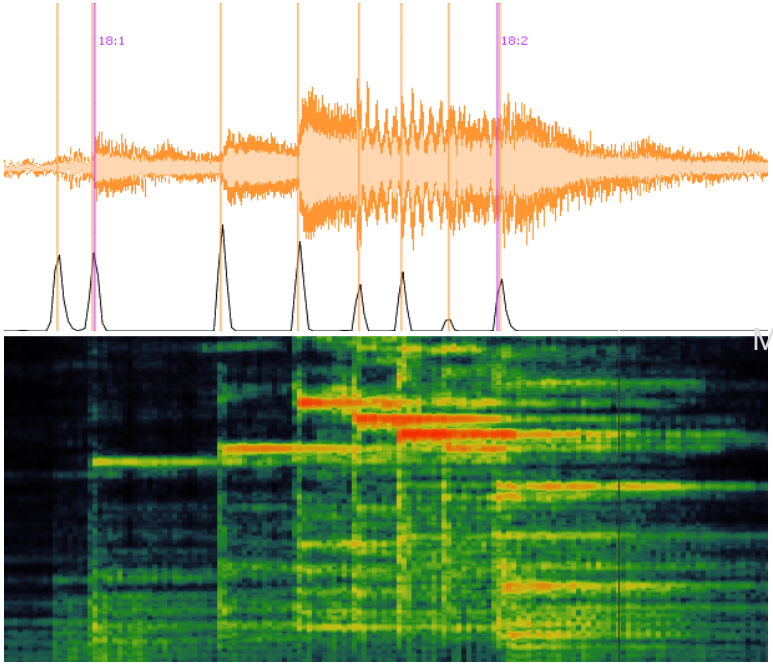


Manual correction of taps

Using audio annotation plugins for Sonic Visualiser

http://www.sonicvisualiser.org

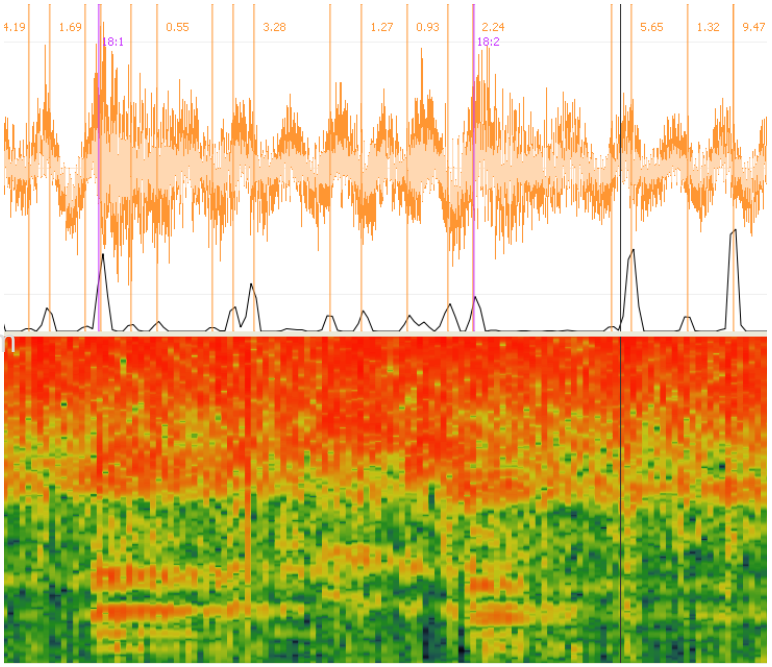
http://sv.mazurka.org.uk



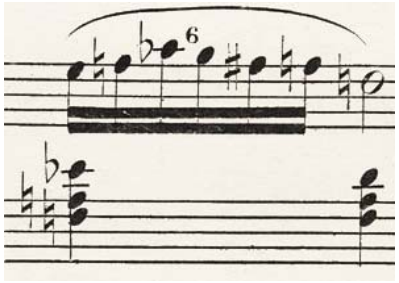
Frederic Chiu, 1999

MzSpectralReflux

MzHarmonicSpectrum

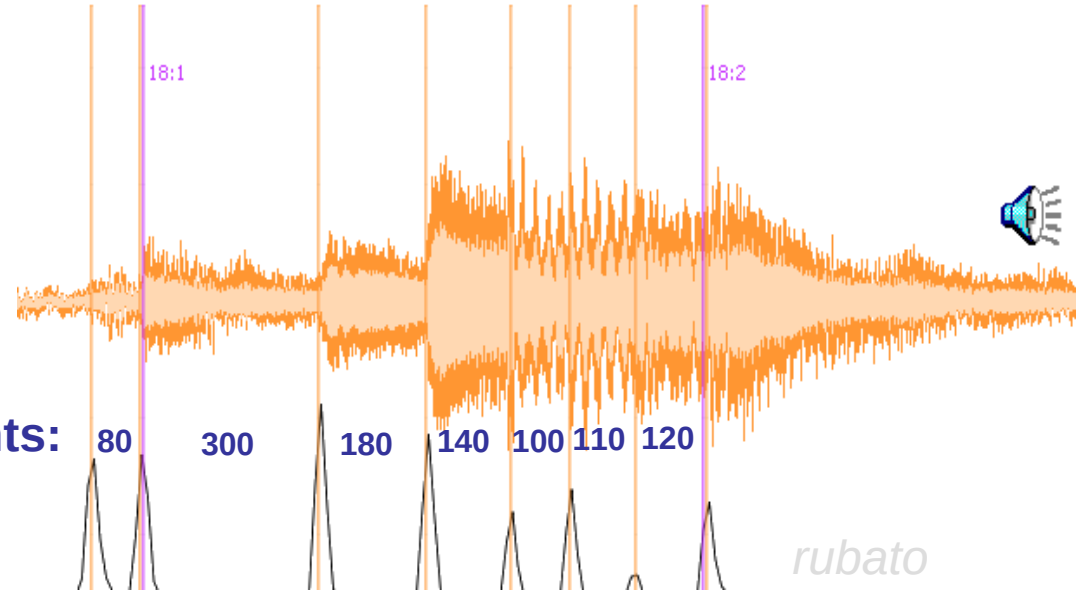


Édouard Risler, 1920



mazurka in A minor, Op. 17, No. 4, m. 18

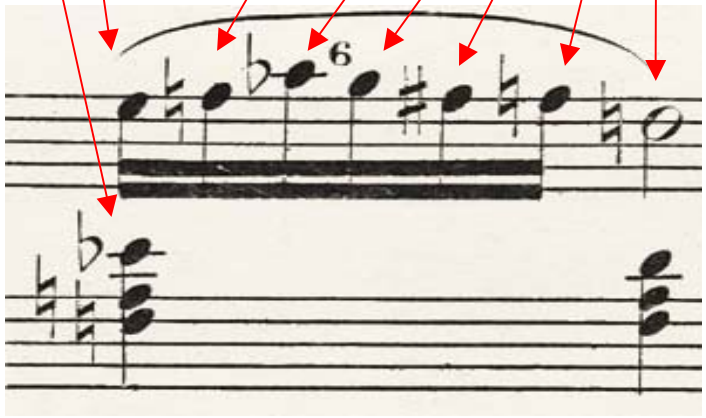
All note events



time between events:
(milliseconds)

rubato

Where does
beat 18:1 start?

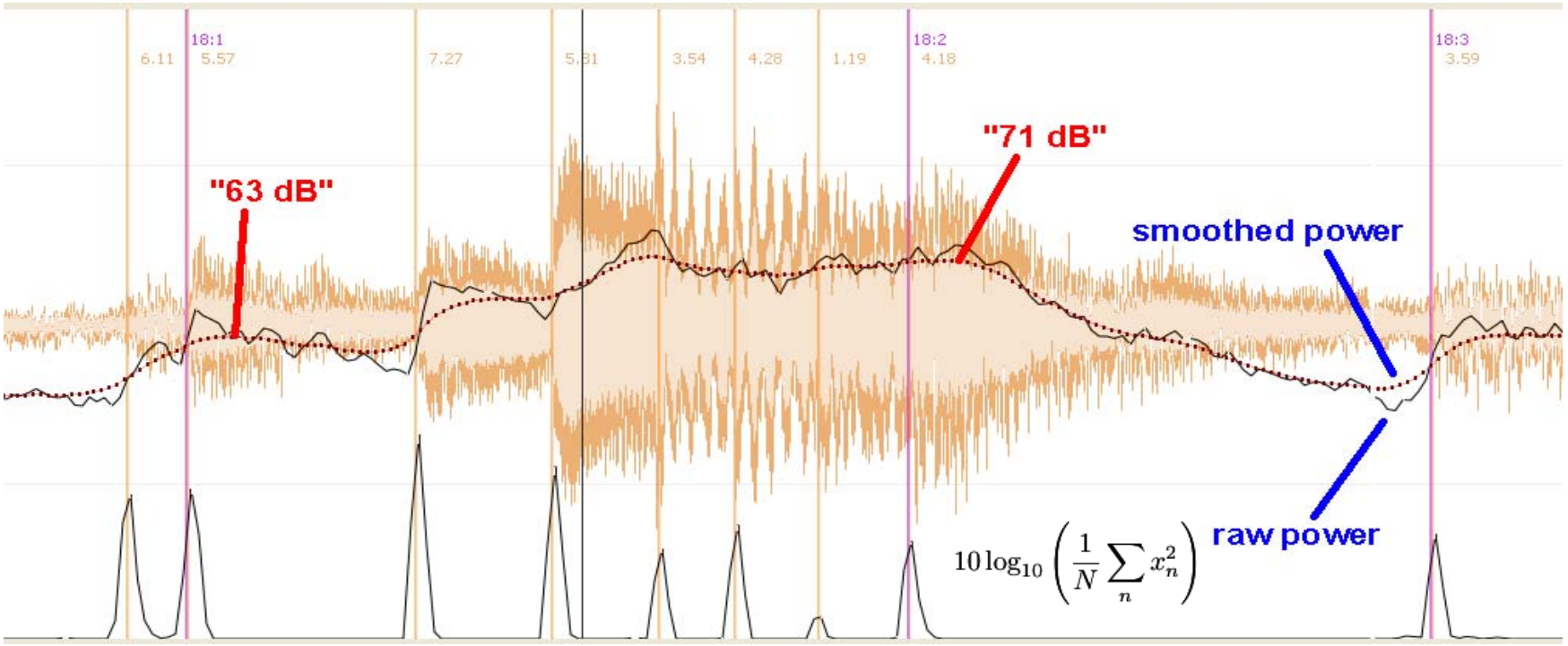


mazurka in A minor, Op. 17, No. 4, m. 18

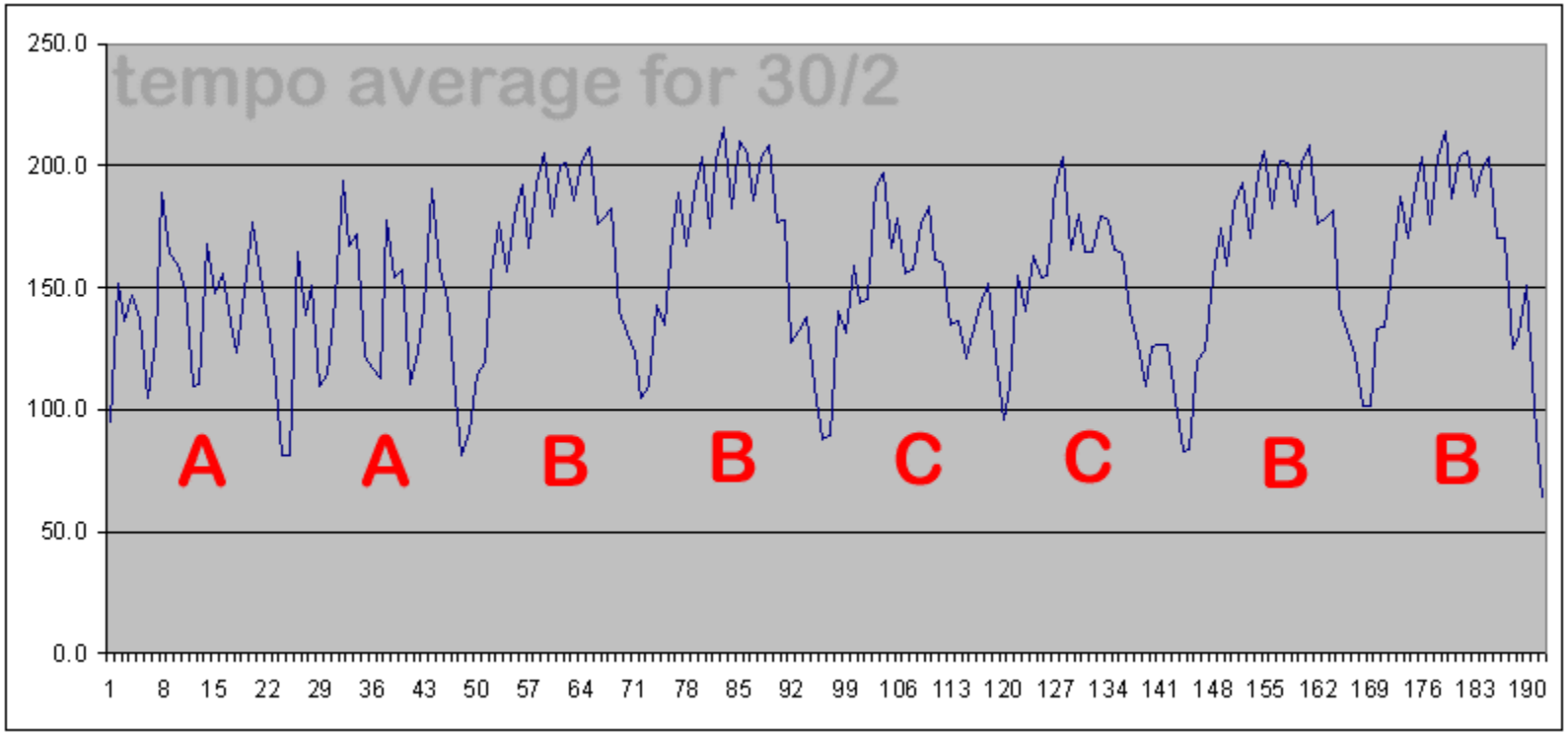
0-25 ms = not audible
25-50 ms = slightly audible
50+ ms = audible
100+ ms = clearly audible

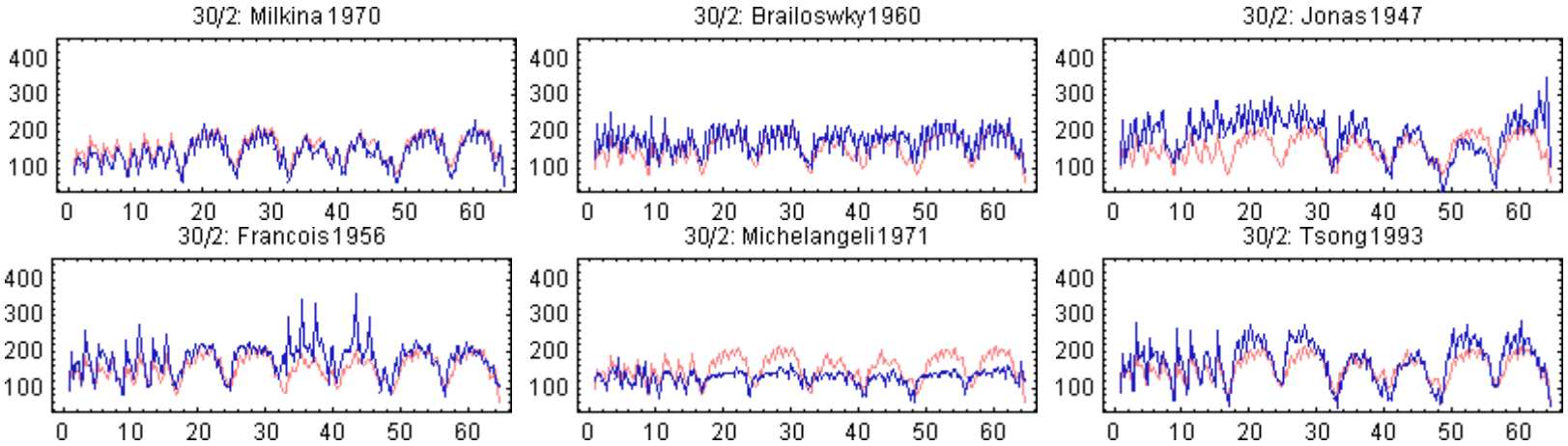
- **non-beat timings extracted with Andrew's program.**
- **individual note loudness extracted with Andrew's program.**

Extracting dynamics

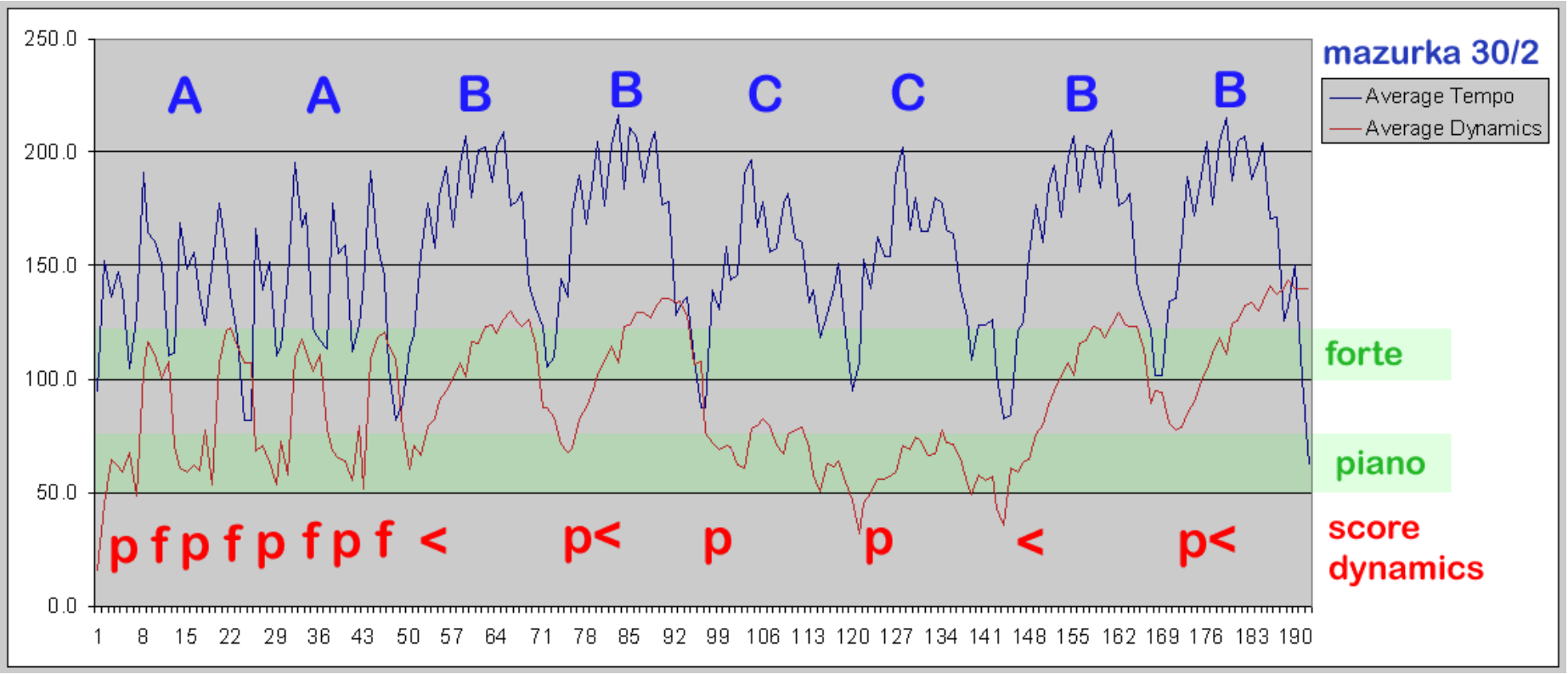


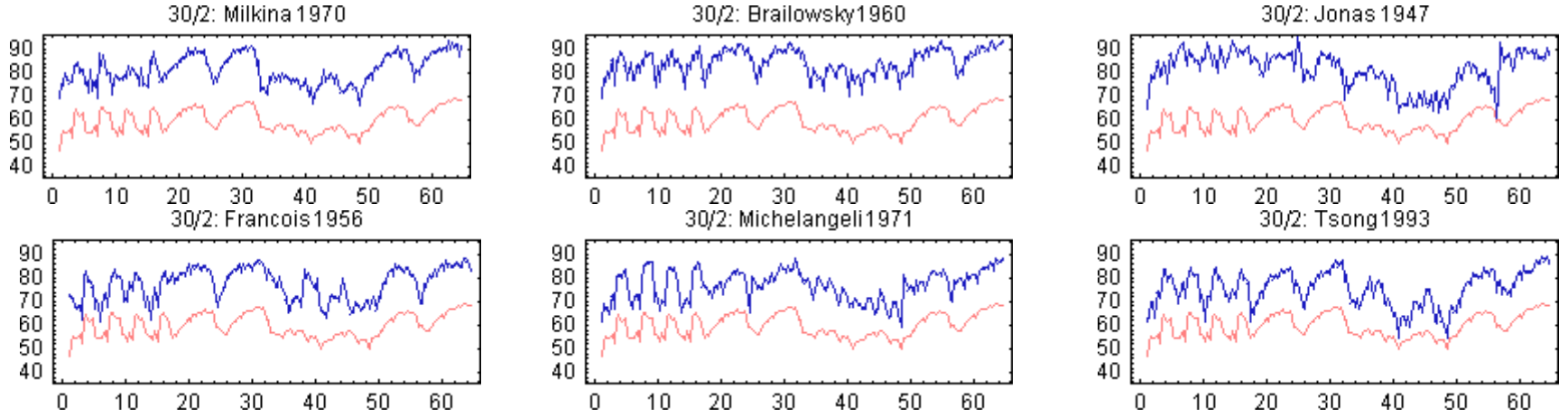
Beat-tempo graphs





Beat-dynamics graphs



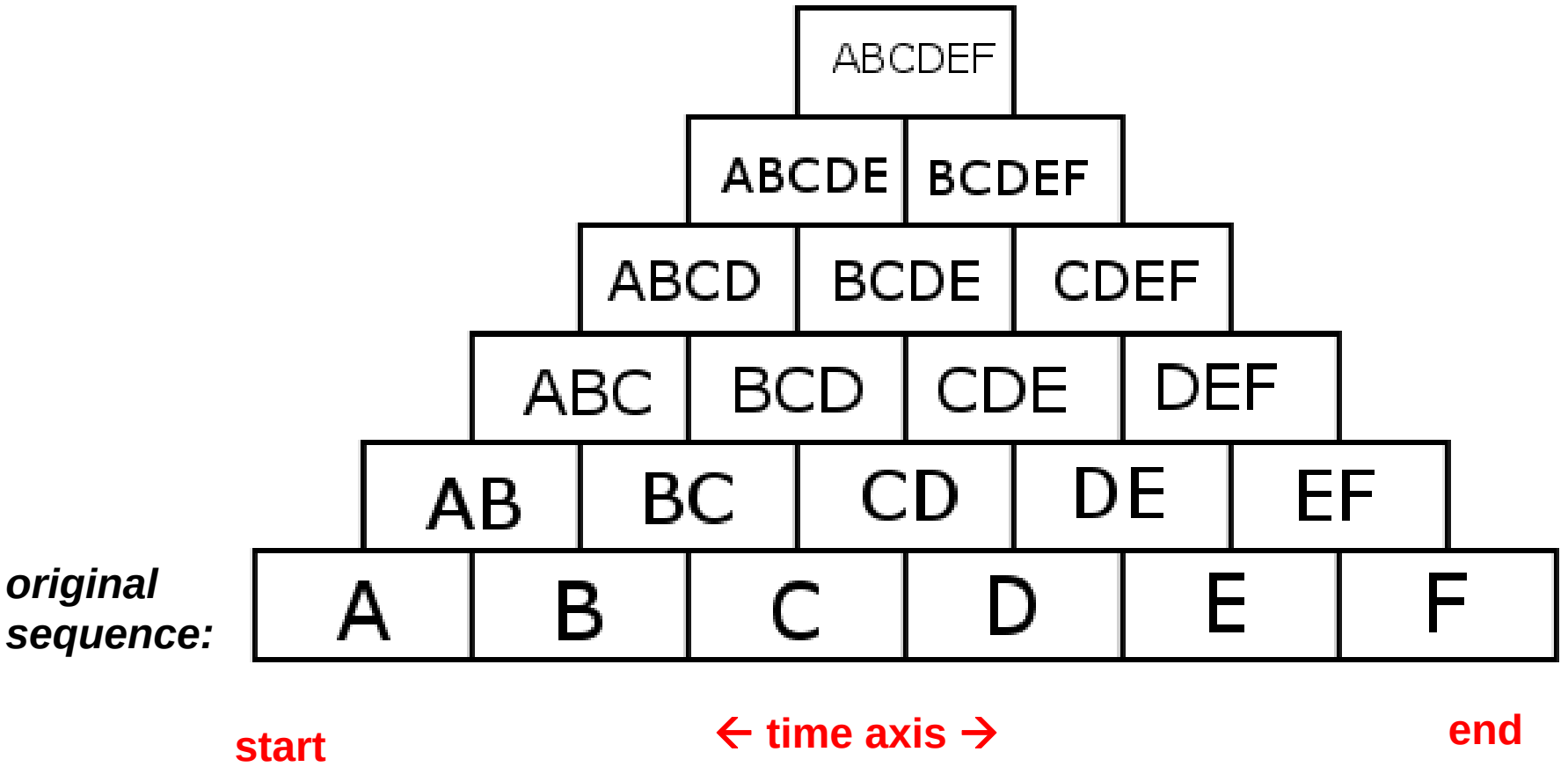


2. Analysis Concepts:

- Scape plots
- Correlation

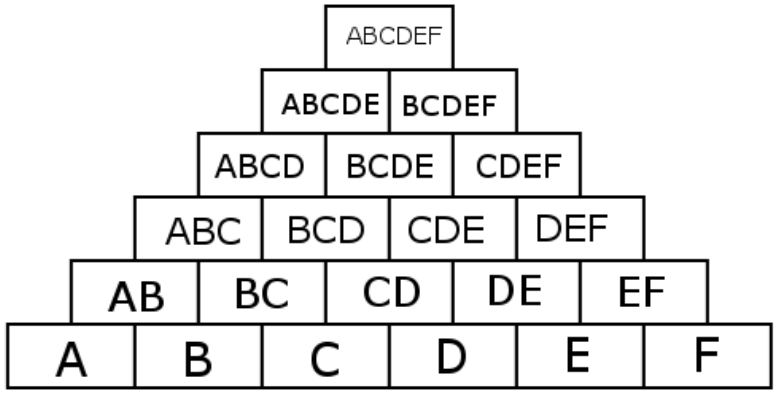
Scape plotting domain

- 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 domain (2)

- 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:



Land***scape***:

background

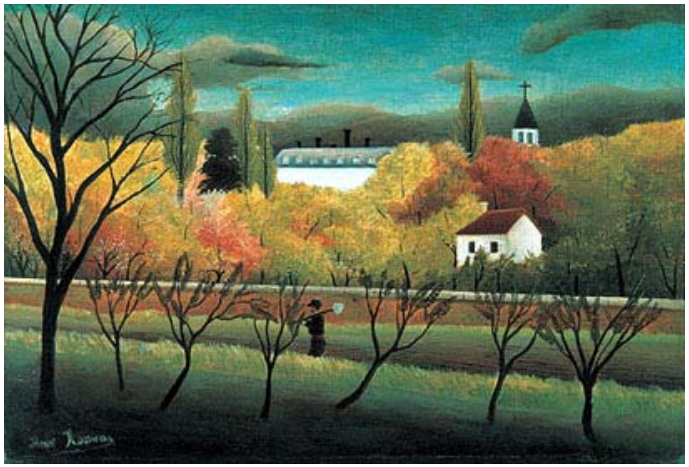
large-scale structures

middleground

small-scale structures

foreground

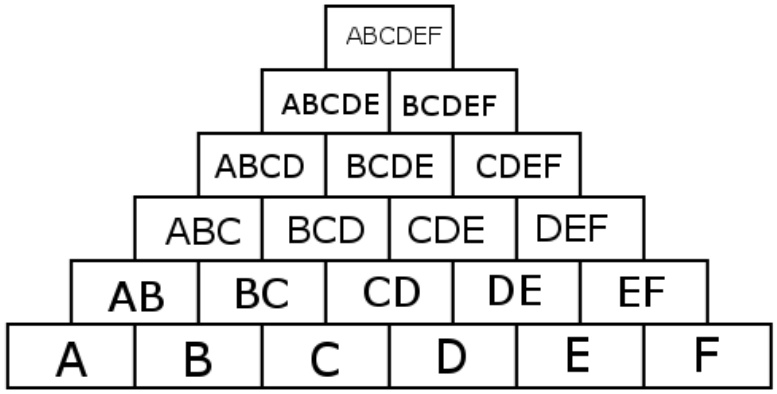
surface features



An Orchard c1896 Henri Rousseau

Scape plotting domain (3)

- 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:



background

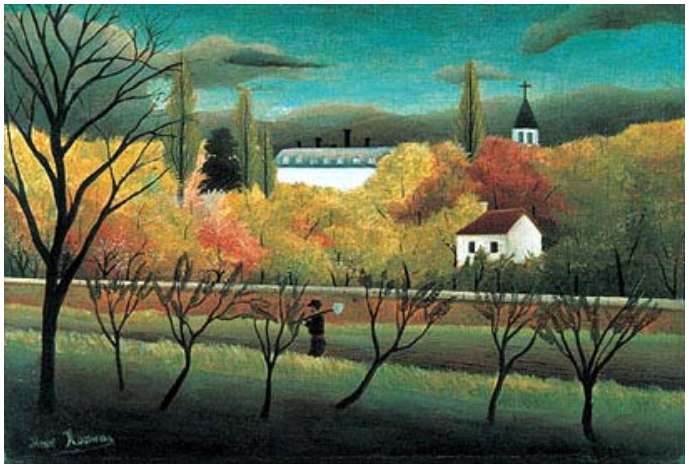
large-scale structures

middleground

small-scale structures

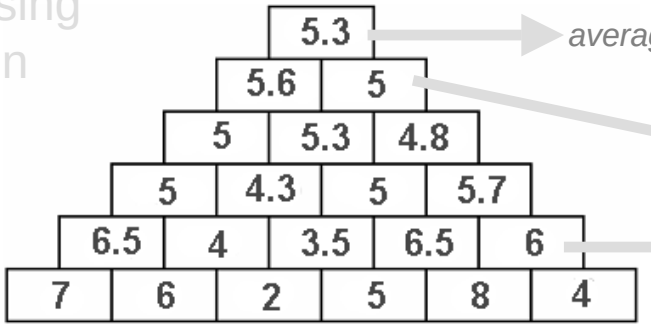
foreground
surface features

Land***scape***:



An Orchard c1896 Henri Rousseau

Example using averaging in each cell:



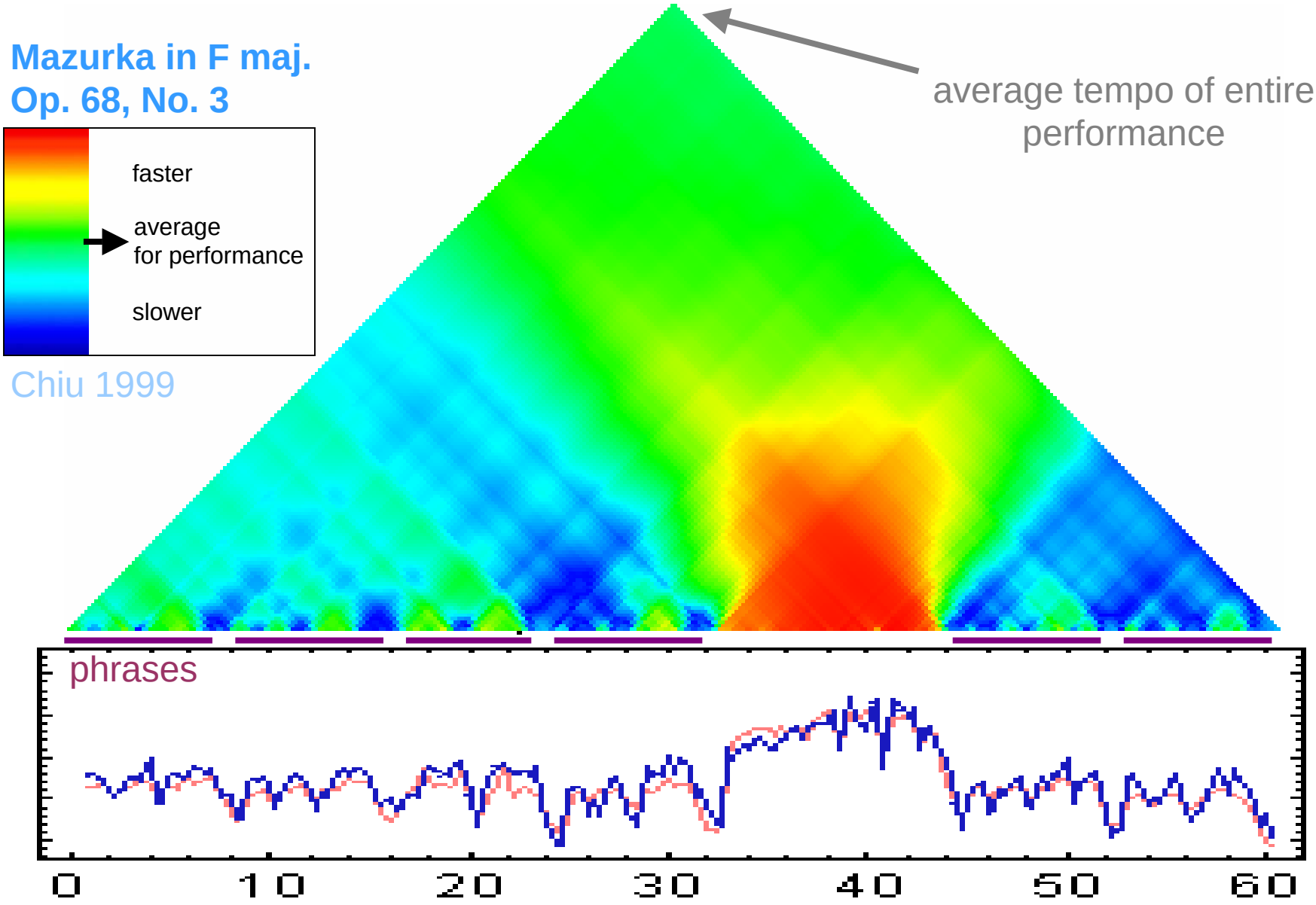
average of all 6 numbers

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

average of last 5 numbers

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

Average-tempo timescapes



Correlation

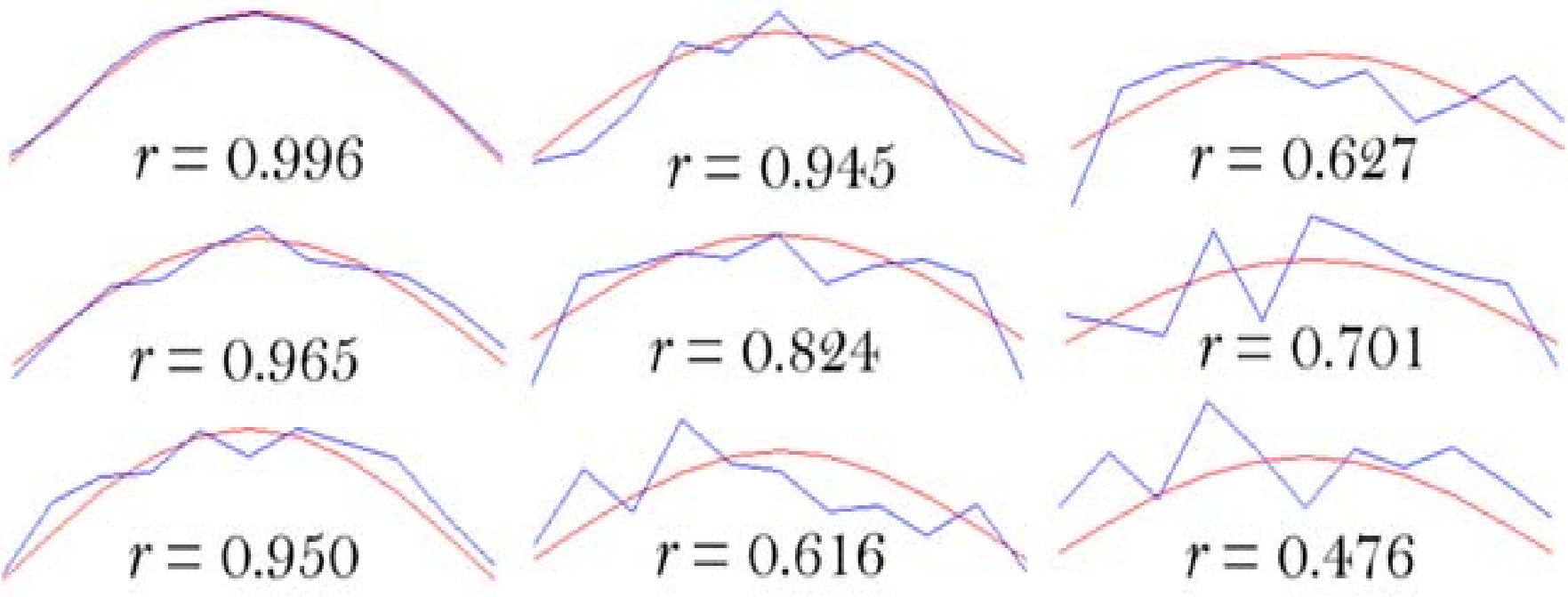
Pearson correlation:

output range: -1.0 to +1.0

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

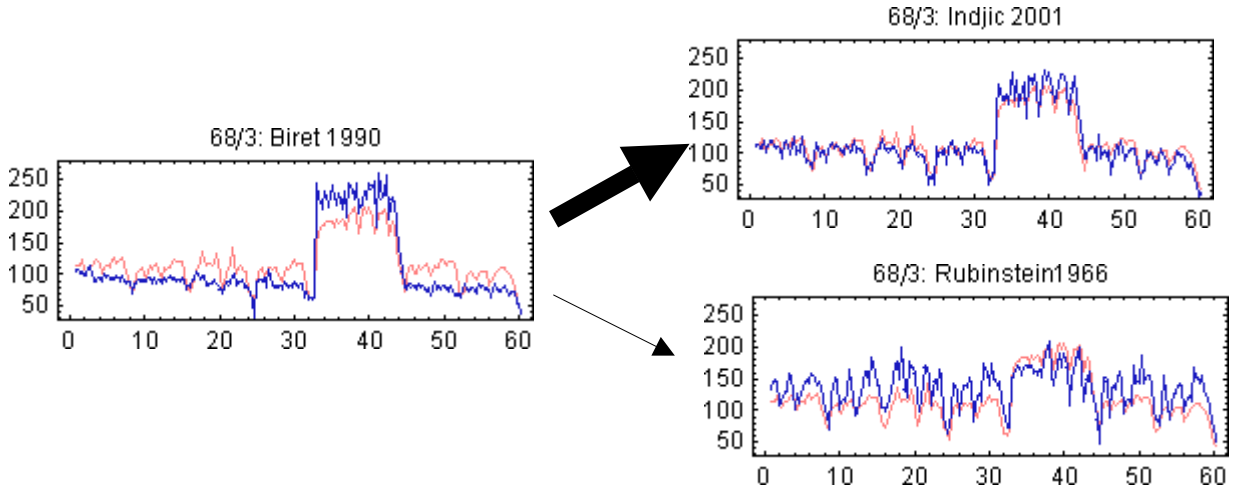
- **Measures how well two shapes match:**

r = 1.0 is an exact match.
r = 0.0 means no relation.



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

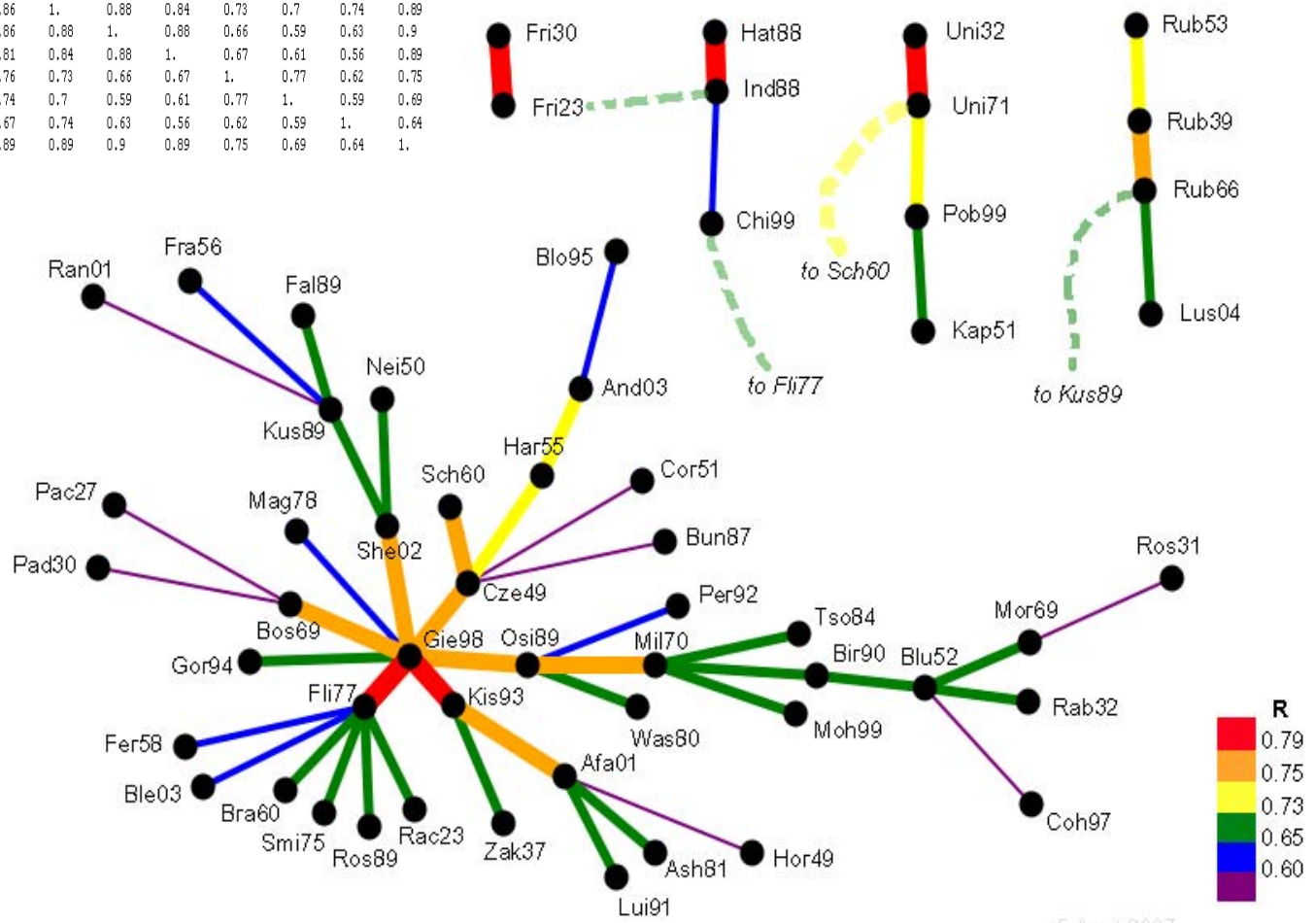
3. Analysis Techniques

- Performance maps
- Correlation scapes
- Performance scapes

Correlation Maps – nearest neighbor

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

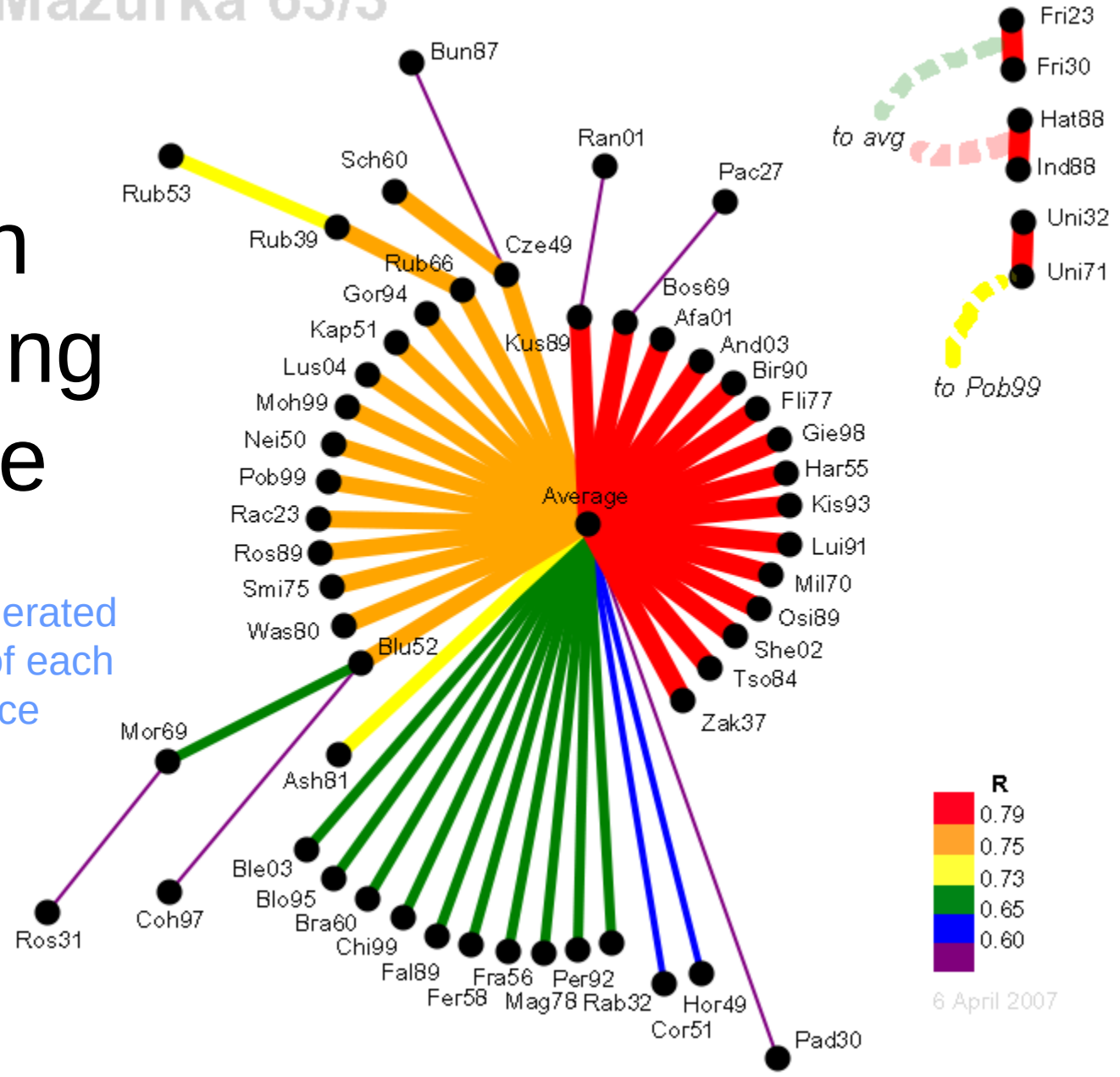
1.	0.92	0.81	0.83	0.95	0.85	0.62	0.5	0.55	0.86
0.92	1.	0.81	0.86	0.91	0.84	0.66	0.55	0.65	0.85
0.81	0.81	1.	0.86	0.86	0.81	0.76	0.74	0.67	0.89
0.83	0.86	0.86	1.	0.88	0.84	0.73	0.7	0.74	0.89
0.95	0.91	0.86	0.88	1.	0.88	0.66	0.59	0.63	0.9
0.85	0.84	0.81	0.84	0.88	1.	0.67	0.61	0.56	0.89
0.62	0.66	0.76	0.73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



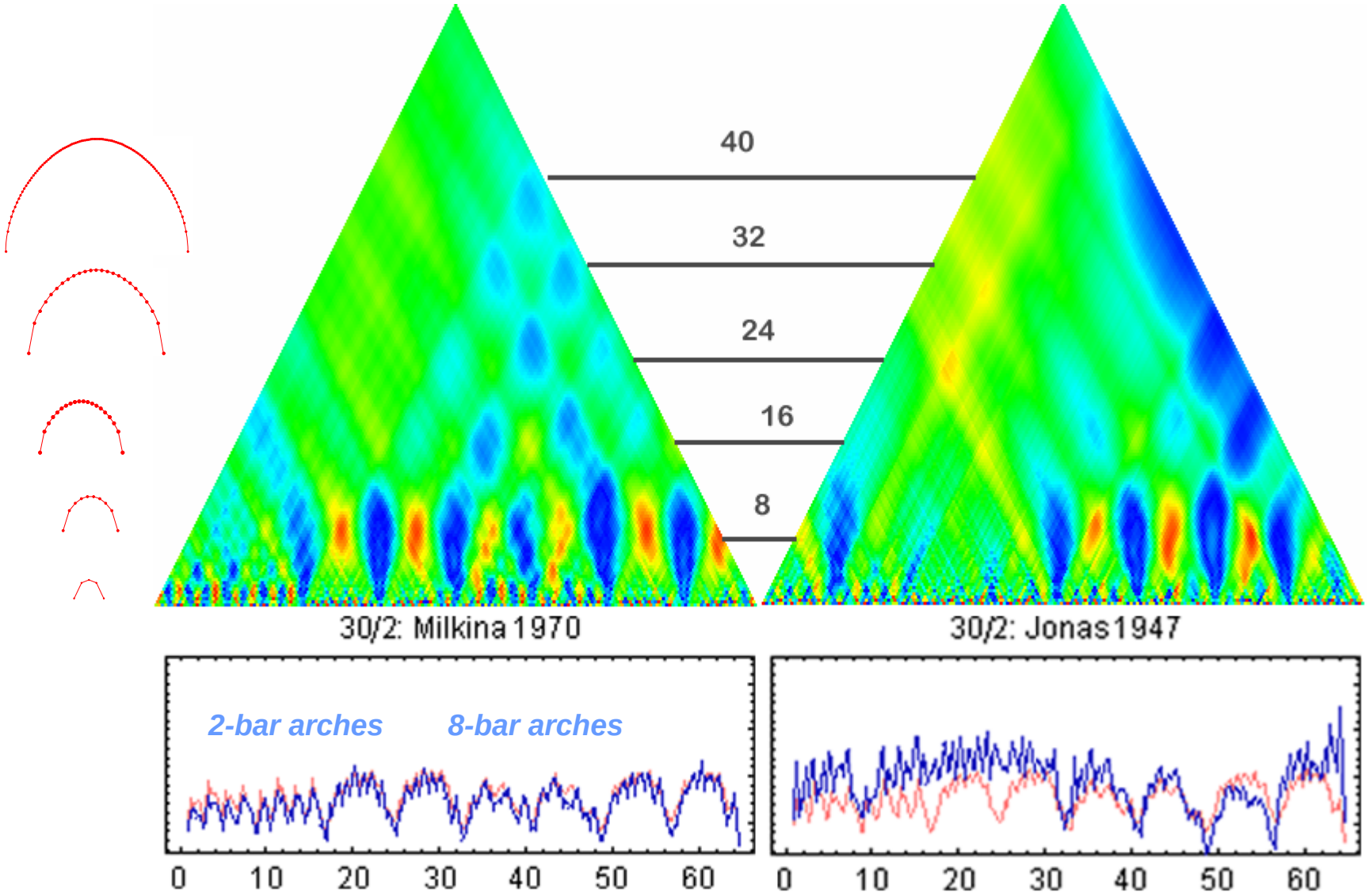
Mazurka 63/3

Correlation Maps – adding the average

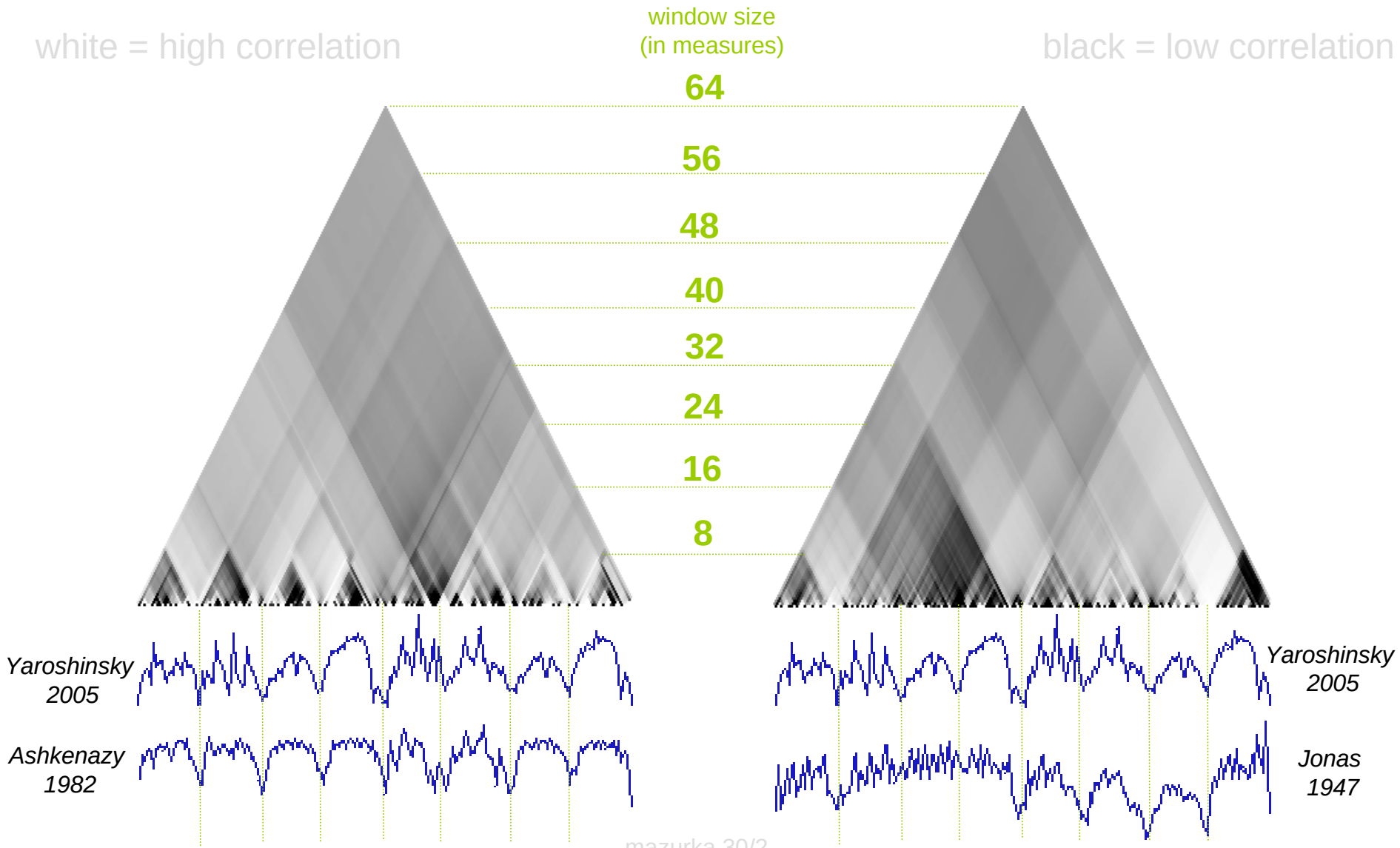
- synthetic average generated by averaging duration of each beat in each performance



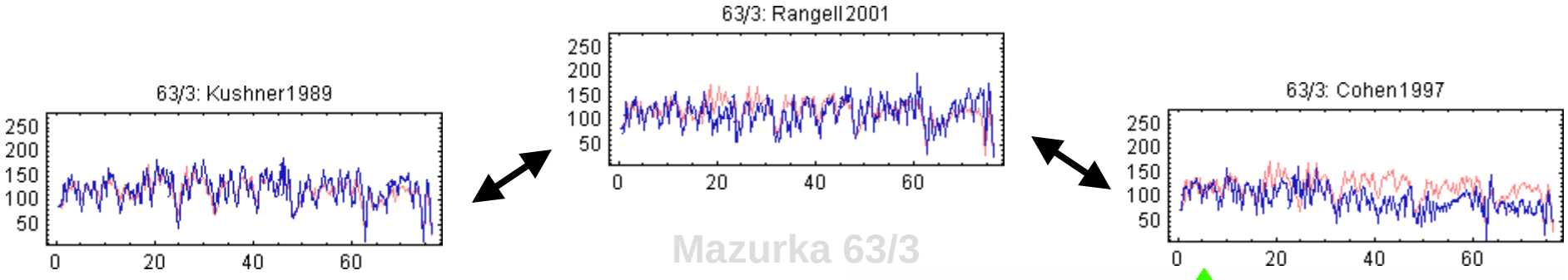
Arch correlation scapes

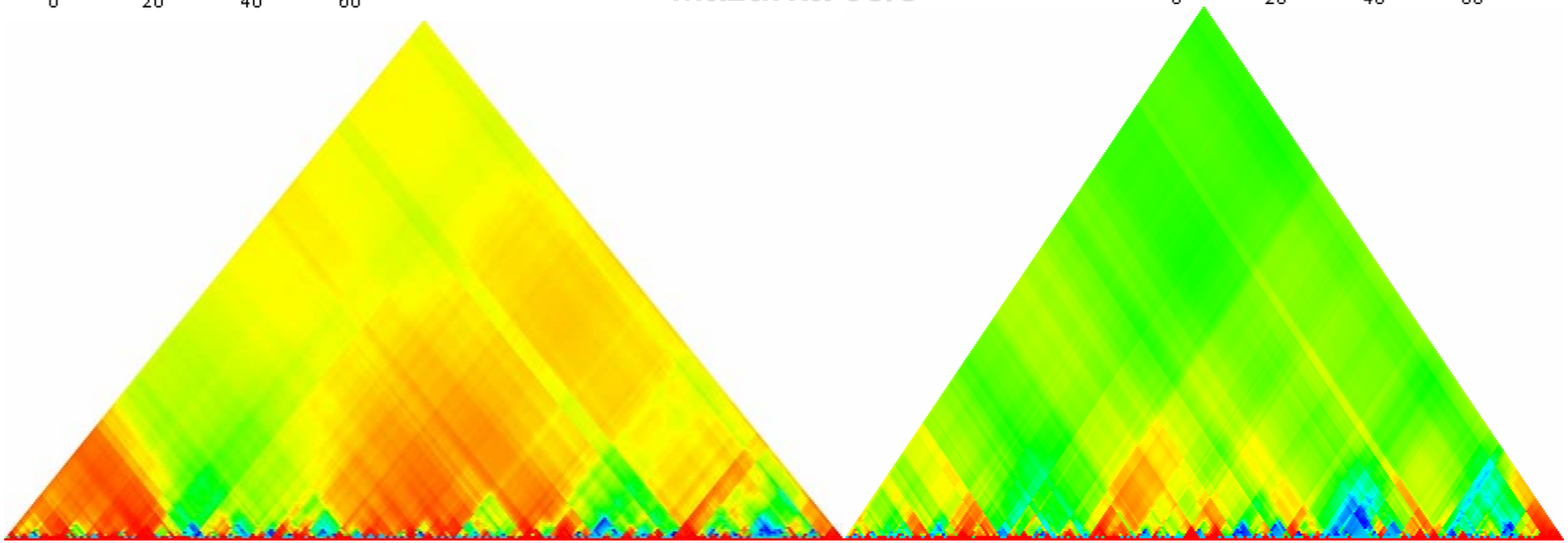


Binary correlation scapes



Binary correlation scapes (2)





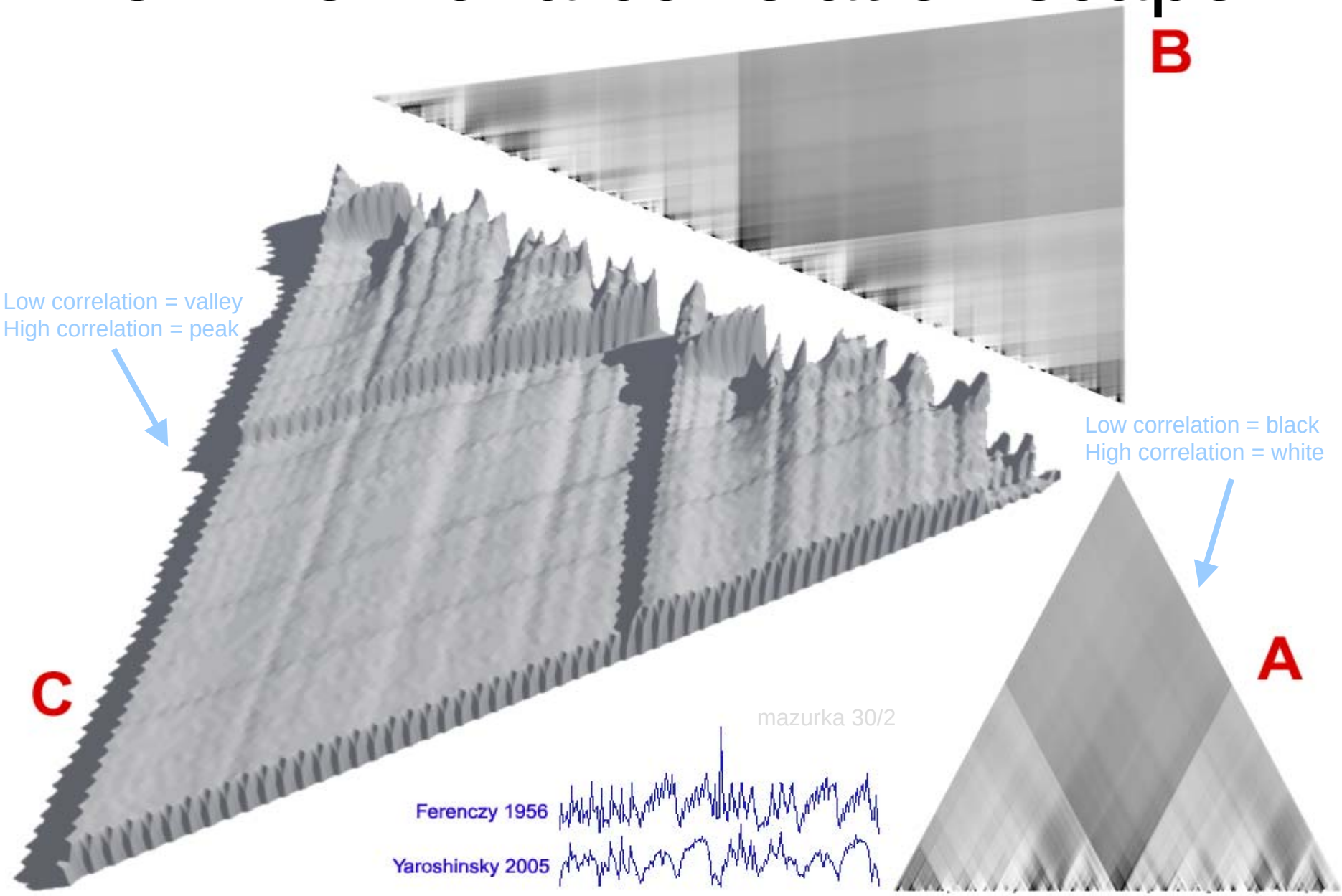
Rangell / Kushner

Rangell / Cohen

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

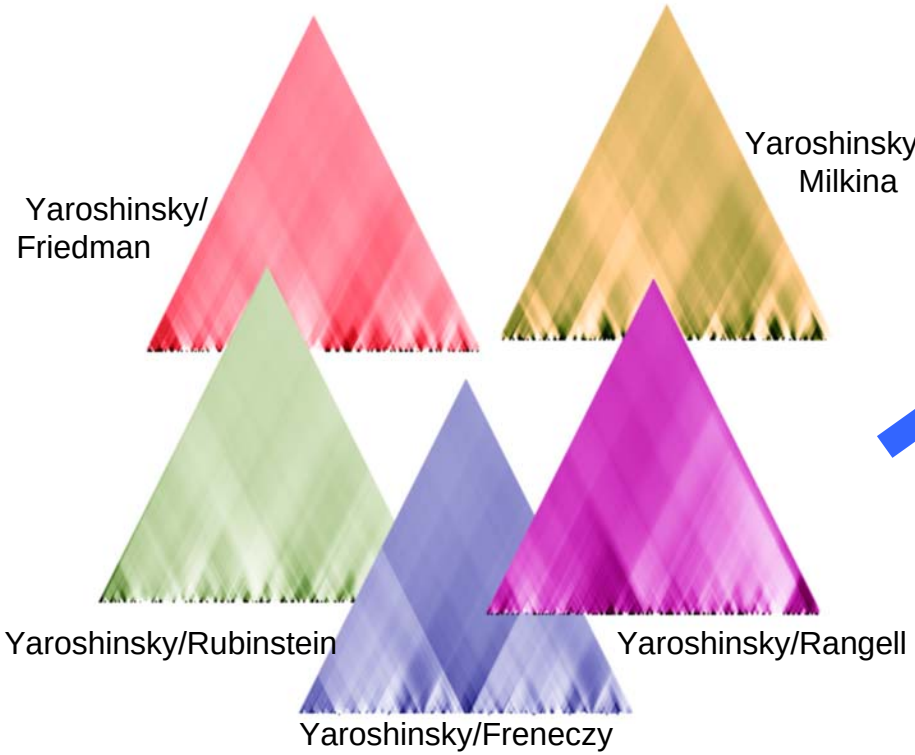
http://mazurka.org.uk/software/online/scape

3D view of a correlation scape



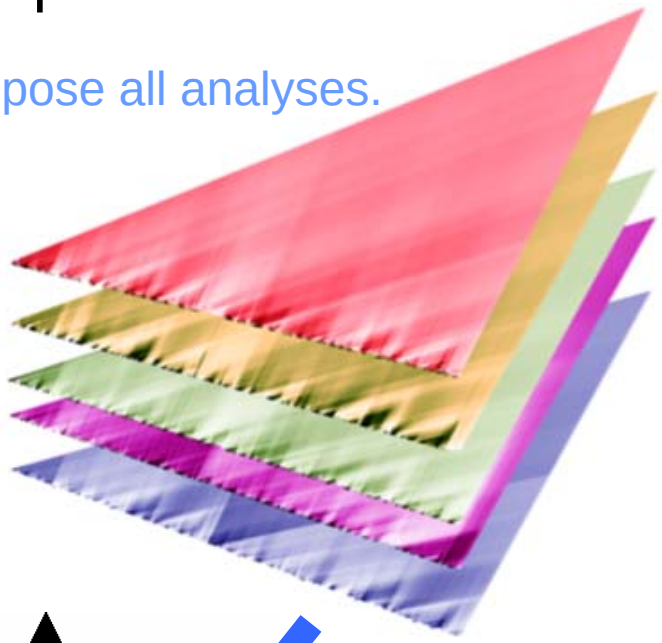
Search for best correlations

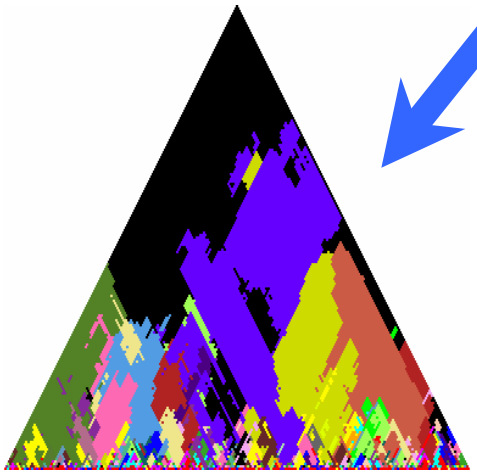
at each point in all plots



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

2. superimpose all analyses.

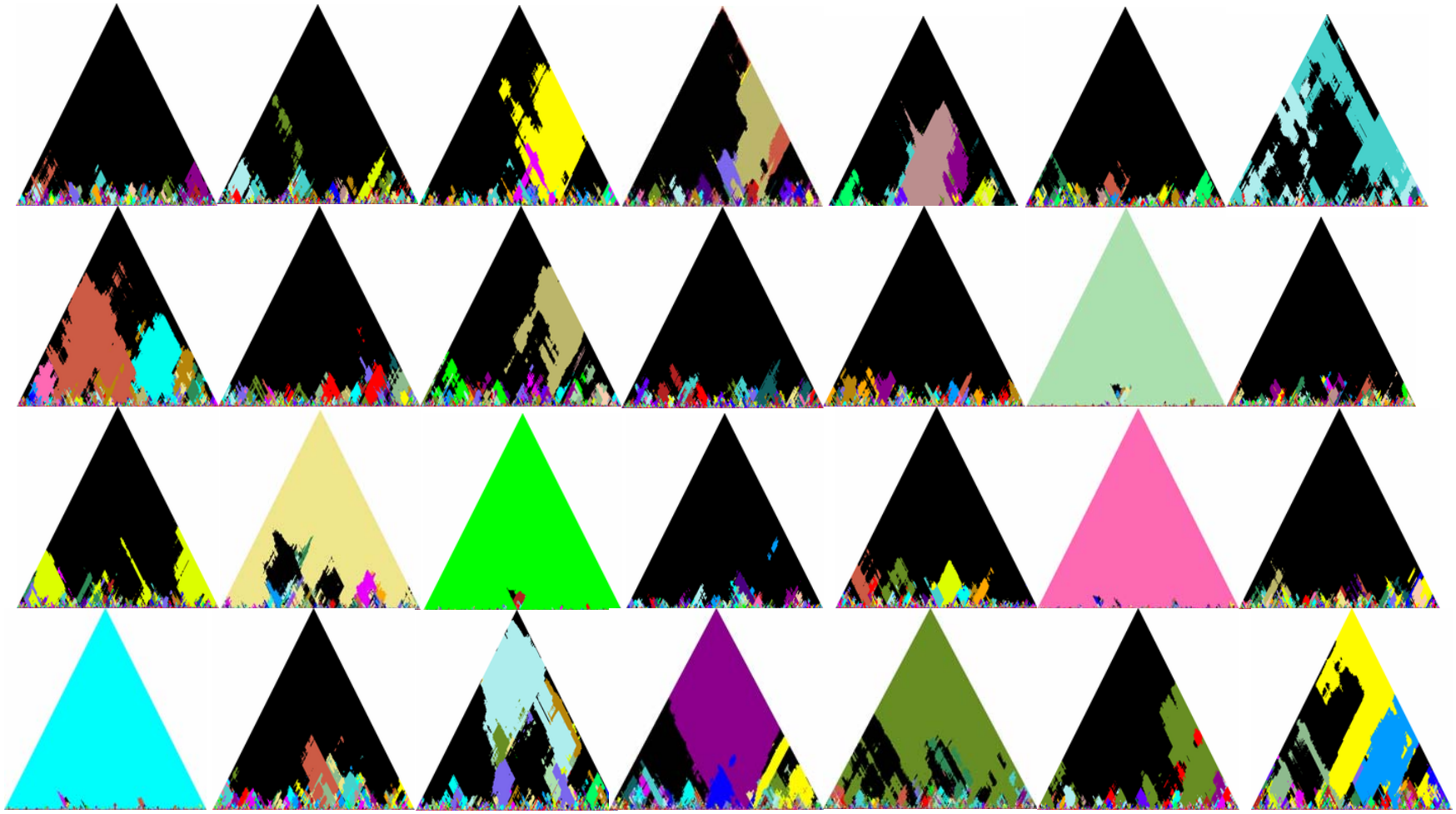




3. look down from above at highest peaks

Perormance correlation scapes

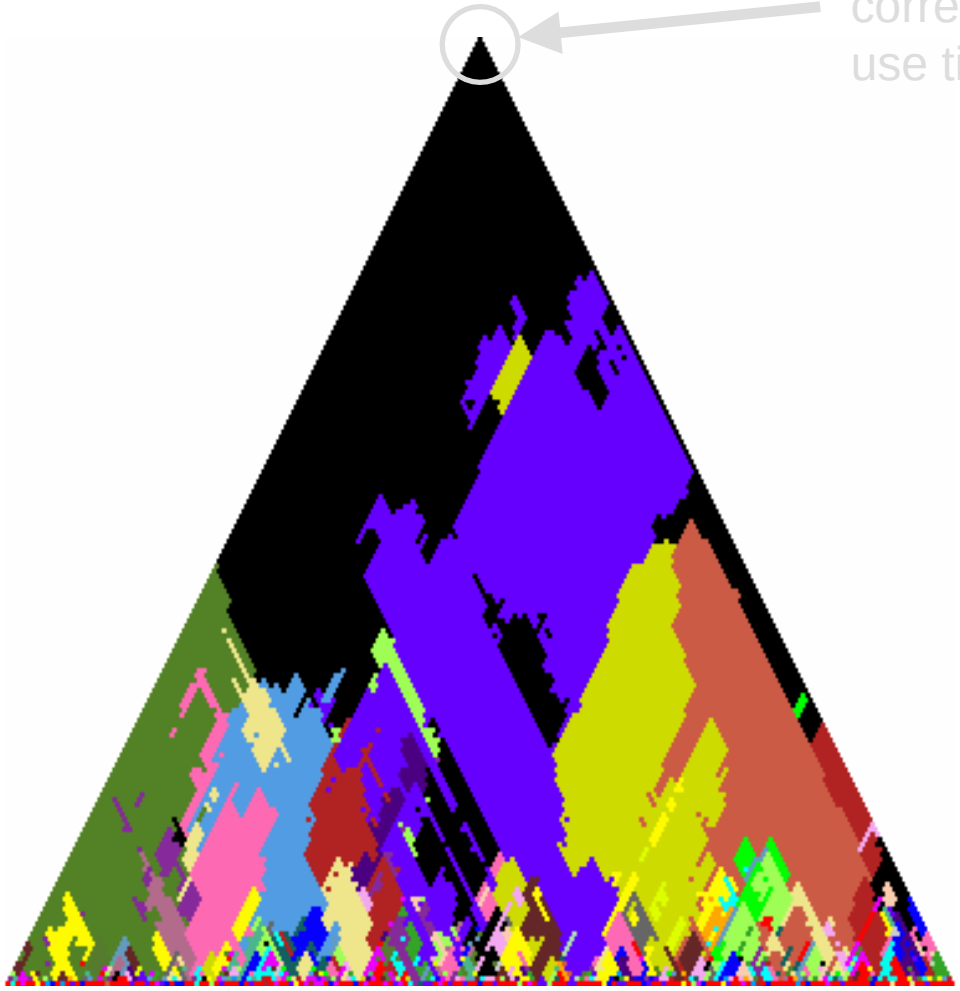
- **Who is most similar to a particular performer at any given region in the music?**



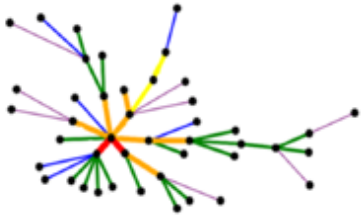
mazurka.org.uk/ana/pcor

mazurka.org.uk/ana/pcor-gbdyn

Nearest neighbors in detail



correlation maps only
use tip of triangle:



Component performances:

29.1%	Average
24.2%	Biret 1990
9.5%	Uninsky 1971
8.4%	Jonas 1947
6.8%	Smith 1975
3.7%	Poblocka 1999
3.1%	Lushtak 2004
3.1%	Fiorentino 1962
2.0%	Francois 1956
1.6%	Cortot 1951
1.5%	Clidat 1994

Yaroshinsky 2005

Mazurka in B minor, 30/2

Causes:

- direction relation (*e.g.*, teacher)
- indirect relation (*e.g.*, school)
- random chance

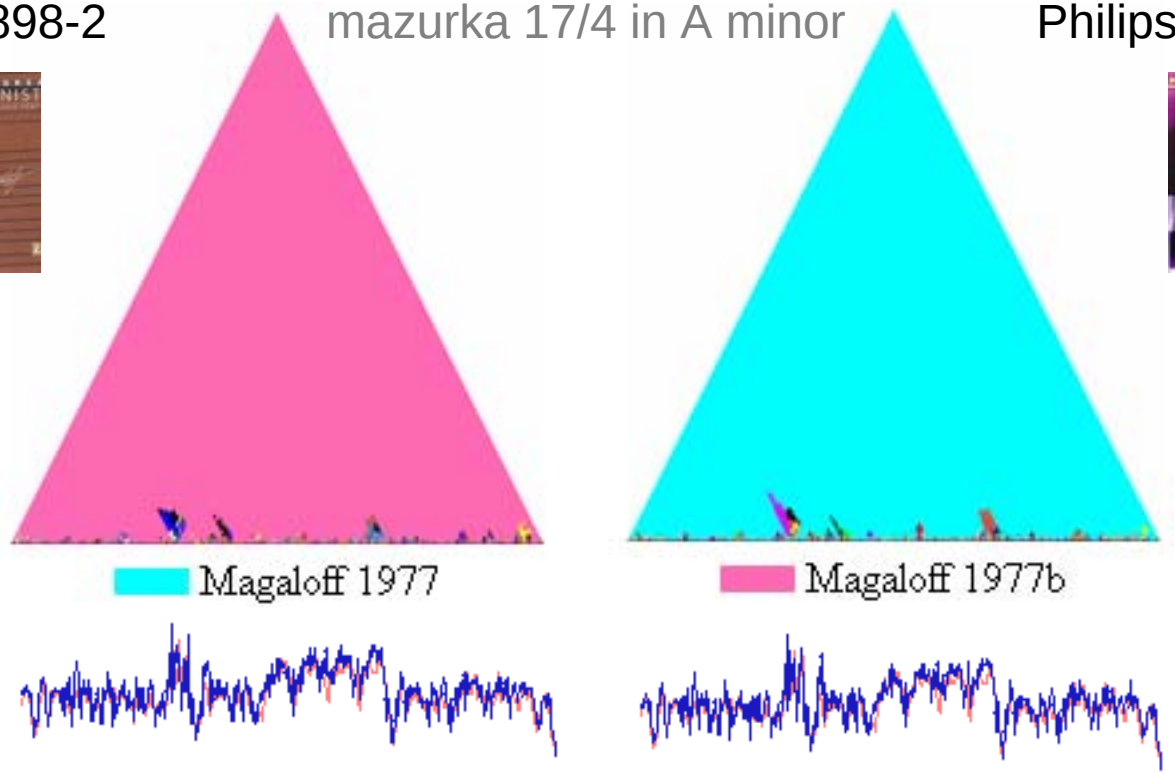
Boring timescape pictures

over-exposed photographs -- 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.

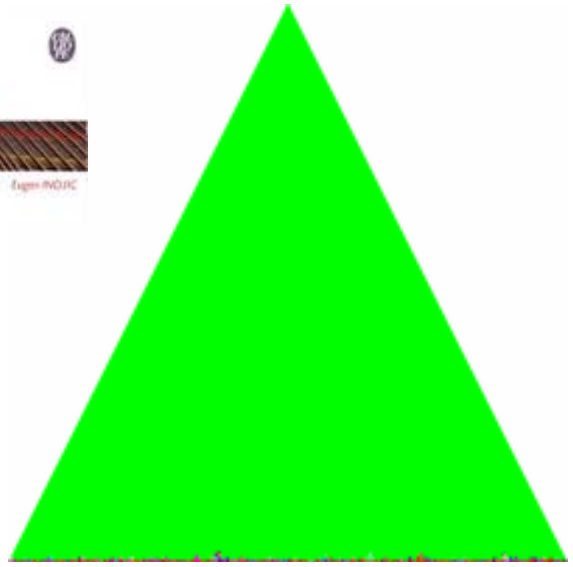
Boring timescape pictures?

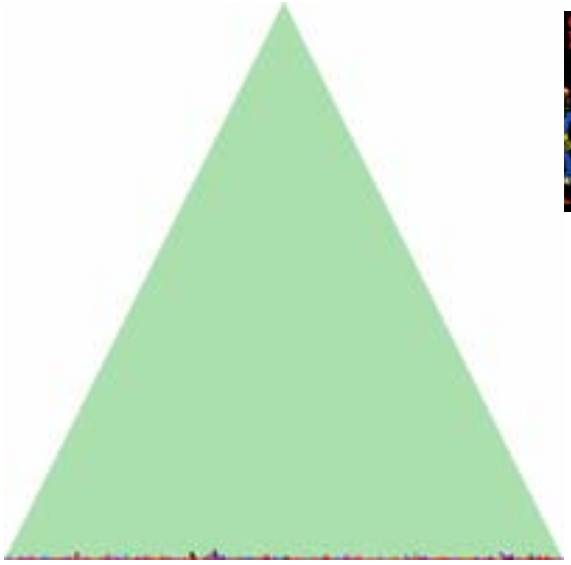
Two difference performances from two different performers on two different record labels from two different countries.

Calliope 3321

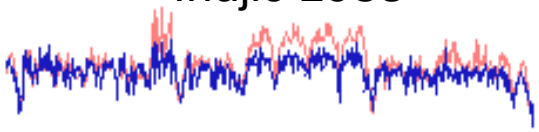
mazurka 17/4 in A minor

Concert Artist 20012

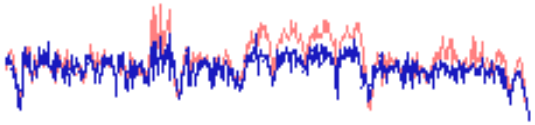




Indjic 1988

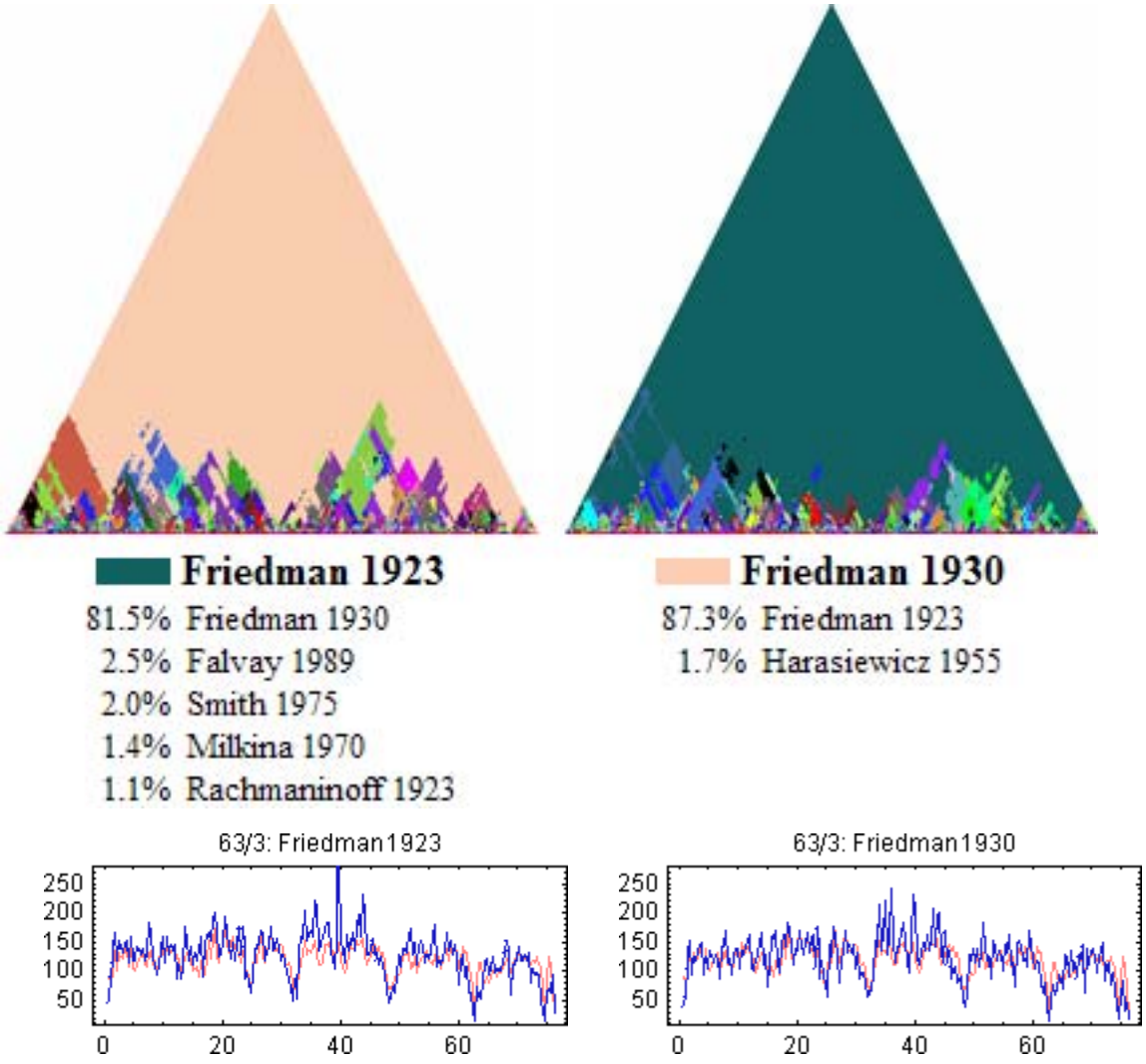


Hatto 1997



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

Timescapes: Friedman



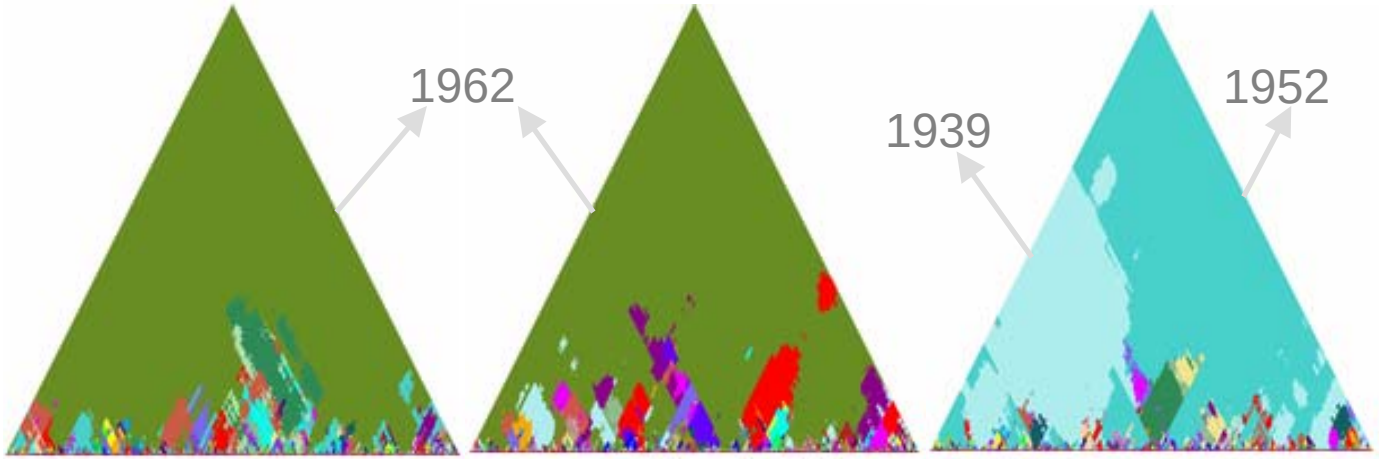
(Mazurka in C-sharp minor, Op. 63, No. 3)

F23	F30
50	41
95	60
118	107
143	134
167	154
122	98
154	125
143	120
136	133
146	146
154	150
118	96
158	124
122	109
122	136
143	127
138	118
132	128
140	120
122	92
128	142
184	146

Same performer over time

Same work; same pianist; different performances

mazurka in A minor 17/4

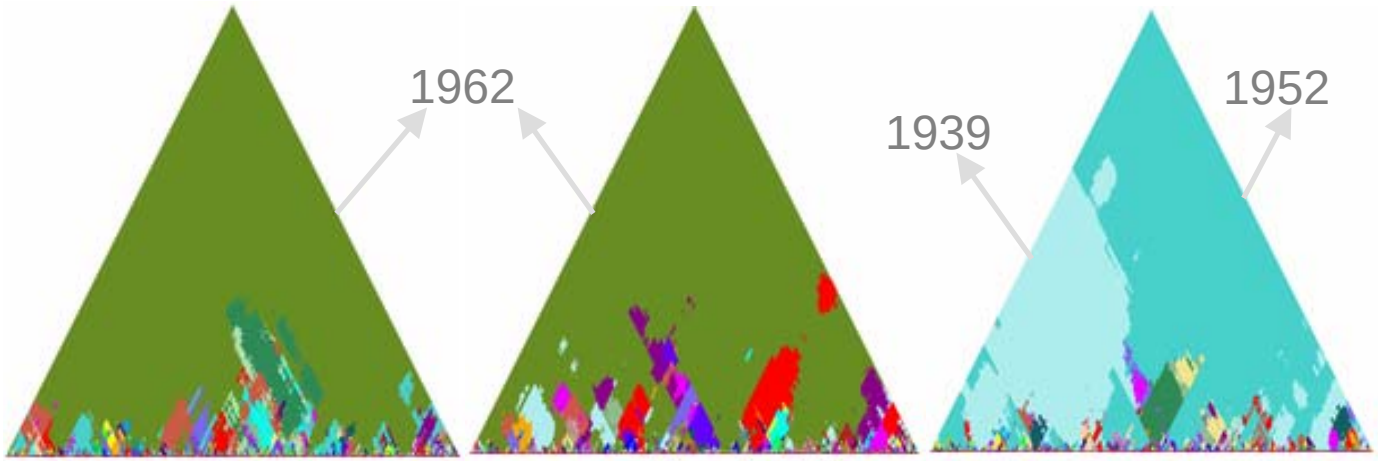


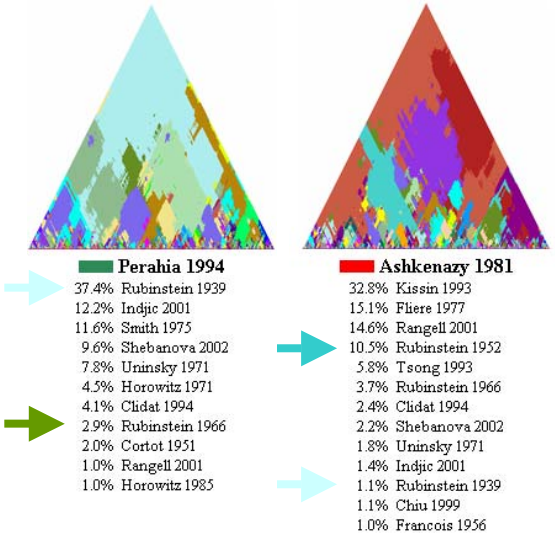
see mazurka.org.uk/ana/pcor/mazurka17-4-noavg

Same performer over time

Same work; same pianist; different performances

mazurka in A minor 17/4





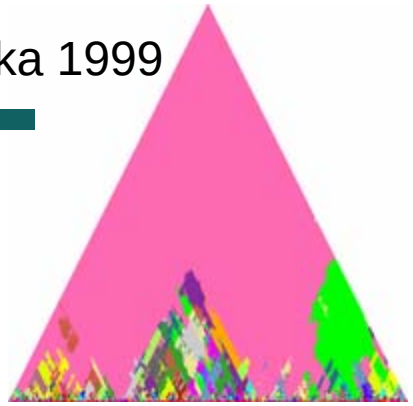
Perahia owns 1939 recording

Ashkenazy owns 1952 recording

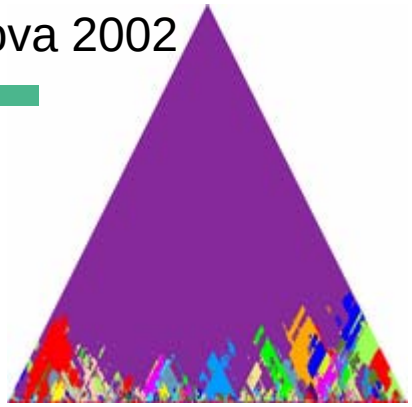
see mazurka.org.uk/ana/pcor/mazurka17-4-noavg

Strong interpretive influences

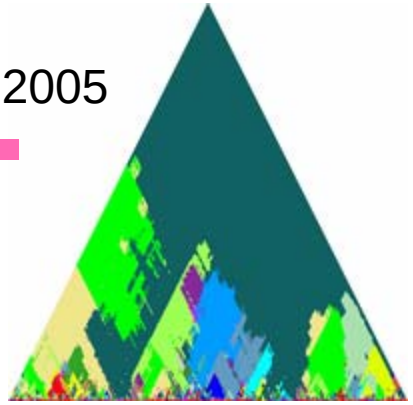
Poblocka 1999



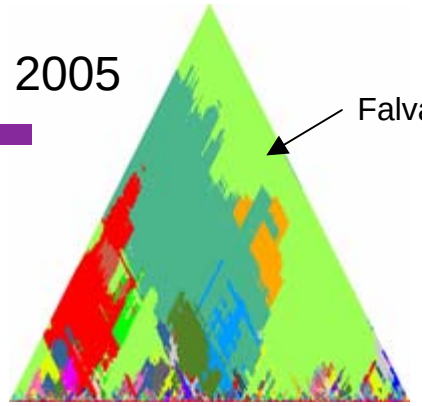
Shebanova 2002



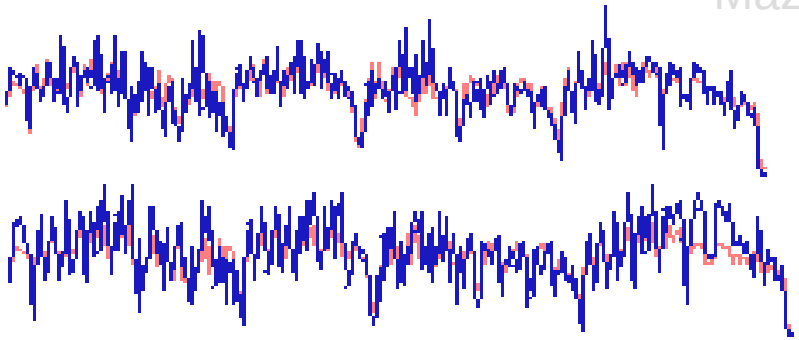
Nezu 2005

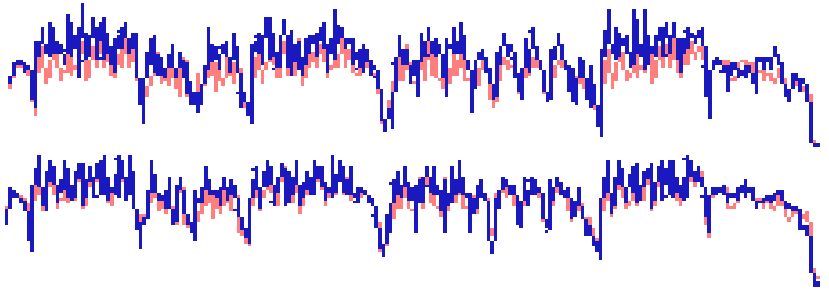


Tsujii 2005

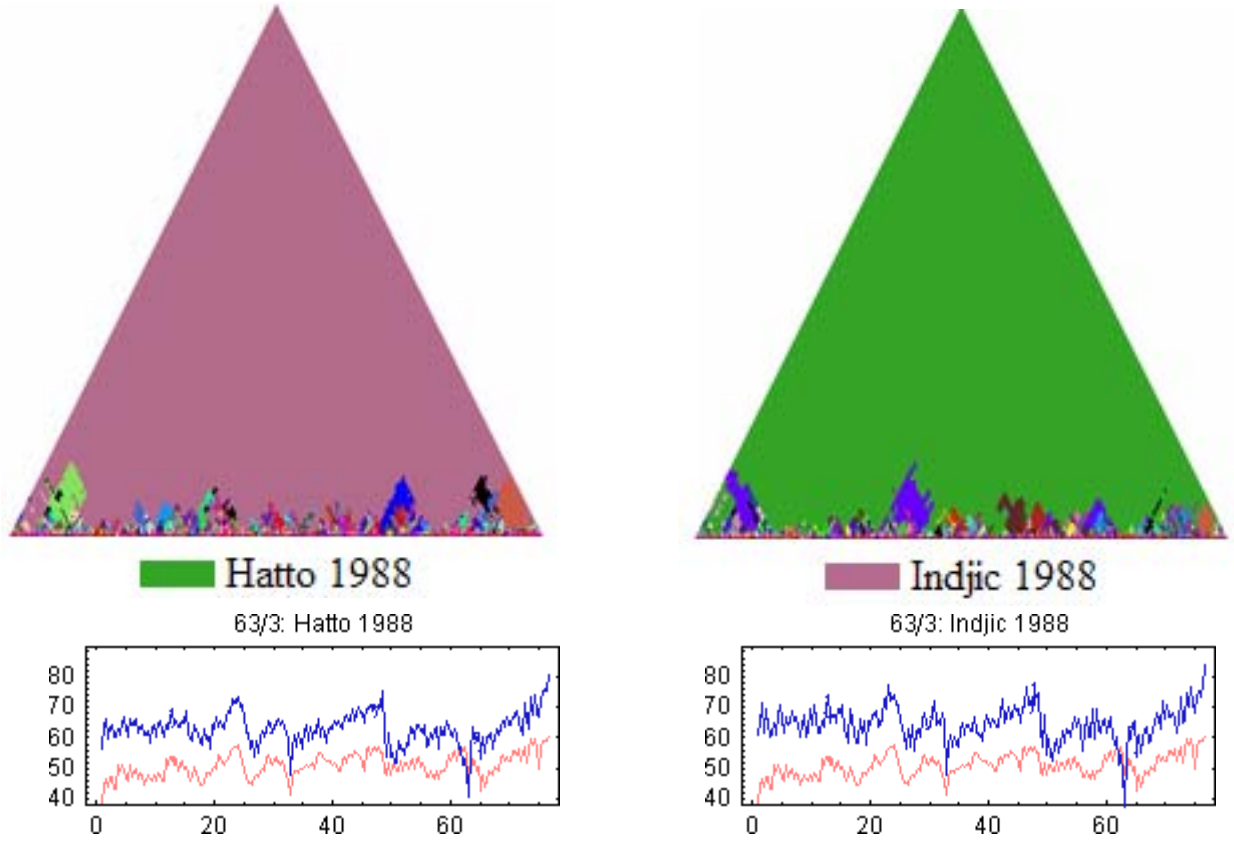


Mazurka in C Major 24/2

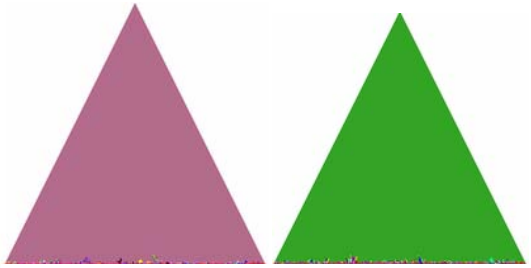




Dynascapes: Hatto & Indjic

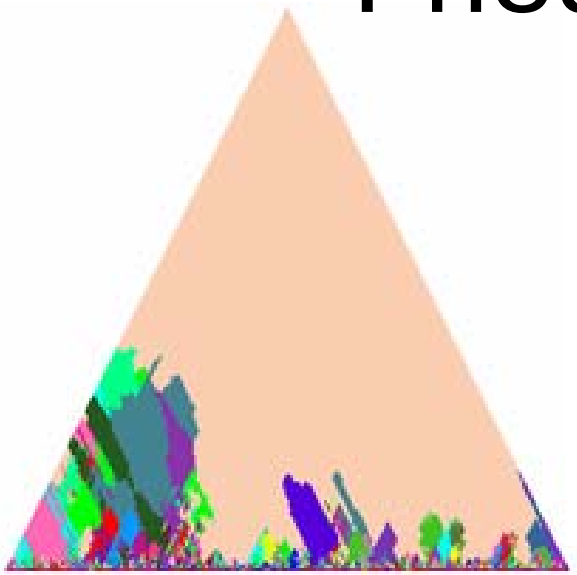


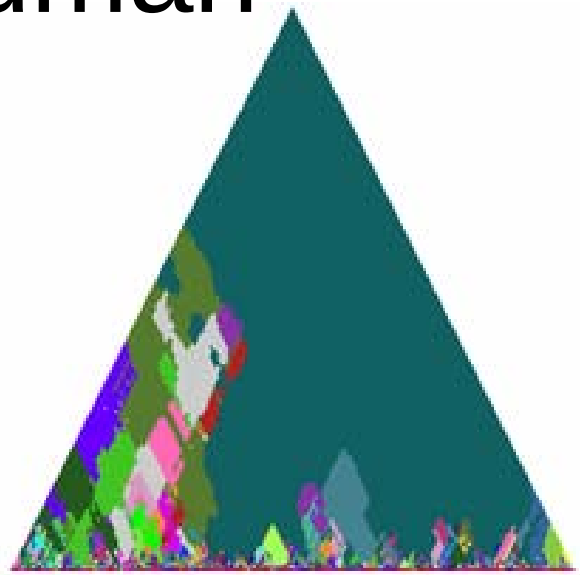
Timescapes:



H	I
56.7	61.3
64.5	64.1
66.0	71.3
60.1	62.3
63.8	69.2
64.0	64.3
61.1	61.0
60.7	61.4
62.9	64.8
61.4	61.4
64.5	67.2
66.9	70.7
63.0	66.1
61.1	62.5
66.0	66.7
65.0	64.5
64.8	65.2
66.3	68.6
62.1	66.1
63.4	66.9
64.1	64.1
61.8	61.0
61.3	64.1
62.1	67.2

Dynascapes: Friedman



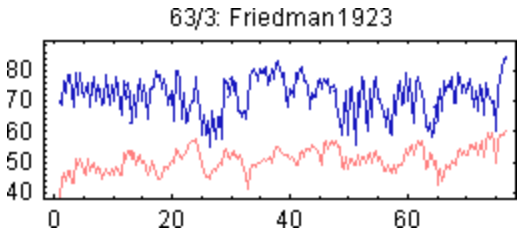


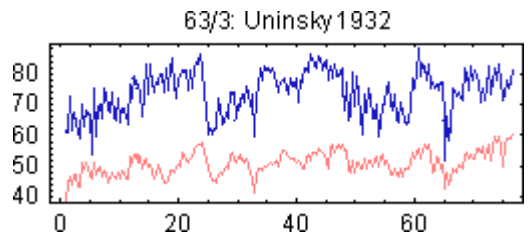
Friedman 1923

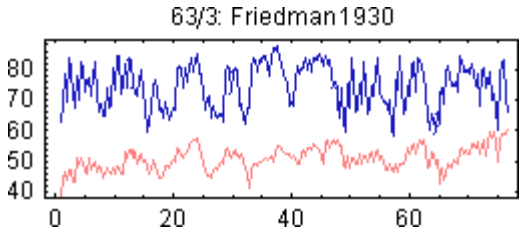
76.4% Friedman 1930
5.6% Uninsky 1932
2.1% Wasowski 1980
1.9% Fliere 1977
1.8% Rachmaninoff 1923
1.8% Chiu 1999
1.6% Rosen 1989
1.6% Rosenthal 1931

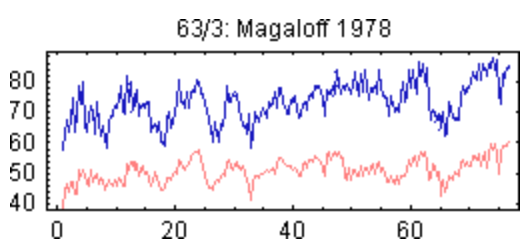
Friedman 1930

67.6% Friedman 1923
7.9% Magaloff 1978
3.8% Gornostaeva 1994
2.8% Paderewski 1930
2.8% Uninsky 1932
2.4% Ashkenazy 1981
2.3% Wasowski 1980
1.6% Fliere 1977
1.0% Rachmaninoff 1923
1.0% Bunin 1987









Timescapes:

Dynascapes: Rubinstein

Rubinstein 1939

26.8% Rubinstein 1952
20.5% Rubinstein 1966
14.6% Milkina 1970
10.2% Hatto 1988
5.1% Bunin 1987
4.8% Cohen 1997
2.8% Falvay 1989
2.3% Moravec 1969
1.2% Brailowsky 1960
1.0% Gornostaeva 1994
1.0% Anderszewski 2003
1.0% Kapell 1951

Rubinstein 1952

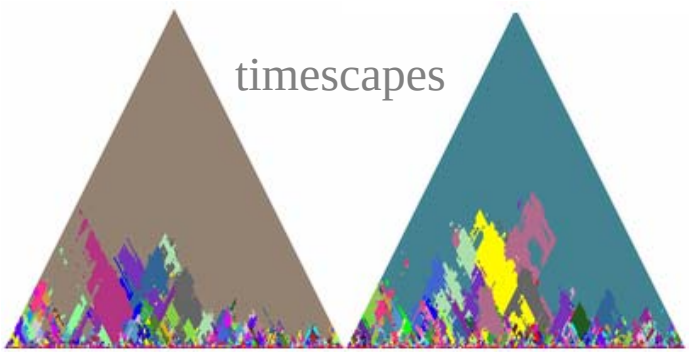
19.8% Rubinstein 1939
16.7% Milkina 1970
14.4% Tsong 1984
7.8% Kissin 1993
3.9% Hatto 1988
3.6% Bunin 1987
3.2% Magaloff 1978
3.0% Lushtak 2004
2.9% Harasiewicz 1955
2.5% Francois 1956
2.5% Osinska 1989
2.3% Rubinstein 1966
2.2% Perlemuter 1992
2.0% Gornostaeva 1994
1.9% Falvay 1989
1.7% Moravec 1969
1.5% Cohen 1997

Rubinstein 1966

46.6% Tsong 1984
26.7% Mohovich 1999
4.2% Rubinstein 1952
3.0% Hatto 1988
2.7% Milkina 1970
1.6% Luisada 1991
1.5% Indjic 1988
1.4% Zak 1937
1.1% Kissin 1993

Alexander Uninsky (1910-1972)

timescapes



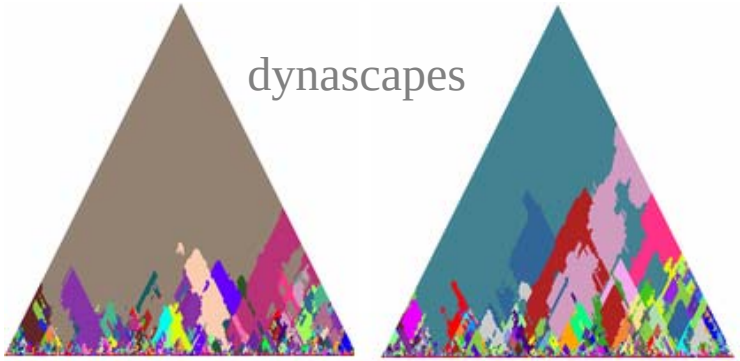
Uninsky 1932

74.1% Uninsky 1971
4.9% Moravec 1969
2.8% Gierzod 1998
2.8% Harasiewicz 1955
1.7% Schilhawsky 1960
1.2% Czerny 1949
1.1% Rabcewiczowa 1932

Uninsky 1971

66.1% Uninsky 1932
6.0% Indjic 1988
5.2% Boshniakovich 1969
2.6% Czerny 1949
2.6% Gierzod 1998
2.1% Schilhawsky 1960
1.9% Milkina 1970
1.7% Harasiewicz 1955

dynascapes



Uninsky 1932

65.5% Uninsky 1971
7.0% Shebanova 2002
4.7% Rachmaninoff 1923
3.8% Friedman 1930
1.8% Ashkenazy 1981
1.7% Luisada 1991
1.3% Horowitz 1949

Uninsky 1971

49.3% Uninsky 1932
10.8% Kapell 1951
7.3% Bunin 1987
6.6% Harasiewicz 1955
3.5% Poblocka 1999
2.1% Gornostaeva 1994
1.7% Smith 1975
1.2% Lushtak 2004

Scapes of Tempo and dynamics:

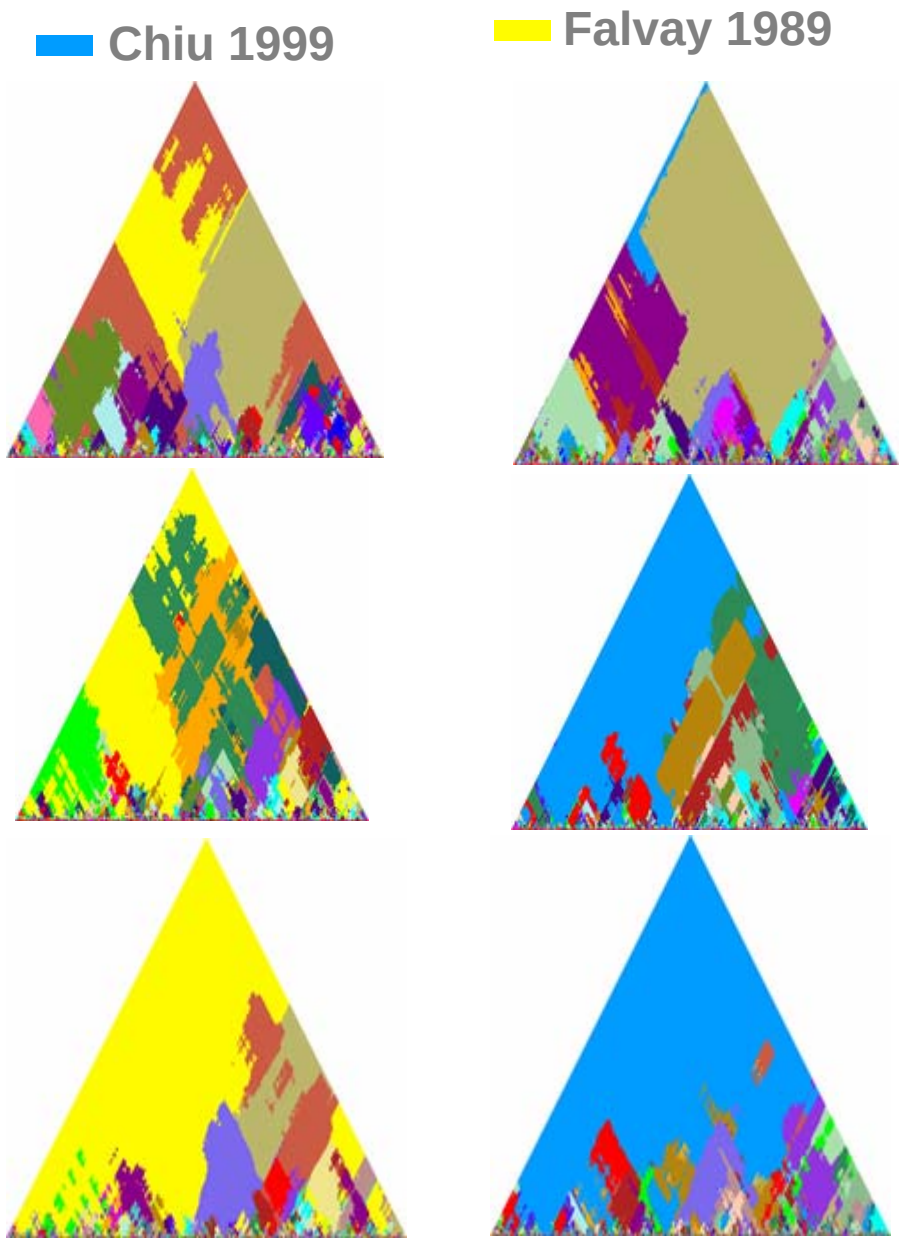
Uninsky 1932

78.9% Uninsky 1971
5.2% Moravec 1969
3.2% Schilhawsky 1960
1.3% Rabcewiczowa 1932
1.3% Rubinstein 1939
1.2% Smith 1975

Uninsky 1971

78.1% Uninsky 1932
4.6% Milkina 1970
4.4% Schilhawsky 1960
1.4% Wasowski 1980
1.2% Smith 1975
1.2% Mohovich 1999

Dynamics + Tempo scapes

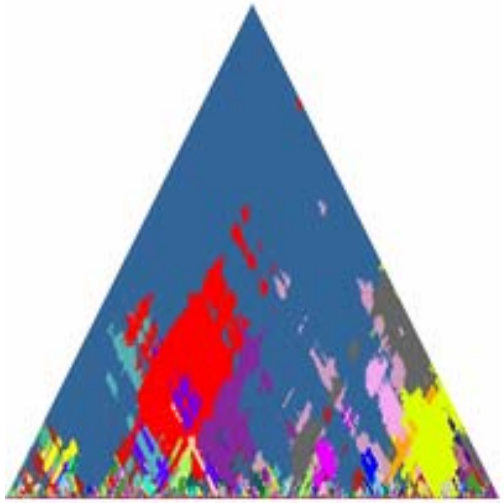


Dynamics + Tempo

Tempo & Dynamics:

Cortot 1951

56.2% Czerny 1949
12.0% Lushtak 2004
8.4% Kapell 1951
5.1% Hatto 1988
2.8% Luisada 1991
1.5% Kissin 1993
1.4% Brailowsky 1960
1.4% Harasiewicz 1955
1.4% Blumental 1952
1.2% Bunin 1987
1.2% Ashkenazy 1981



Czerny 1949

59.1% Harasiewicz 1955
10.7% Afanassiev 2001
5.0% Gierzod 1998
4.1% Kissin 1993
4.0% Cortot 1951
2.9% Kapell 1951
2.2% Kushner 1989
1.8% Lushtak 2004
1.5% Ashkenazy 1981
1.3% Bunin 1987

Halina Czerny-Stefanska studied the piano under her father Stanislaw Czerny, Jozef Turczynski, Zbigniew Drzewiecki and Alfred Cortot in Paris.

Tempo & Dyanmics: Rangell (1)

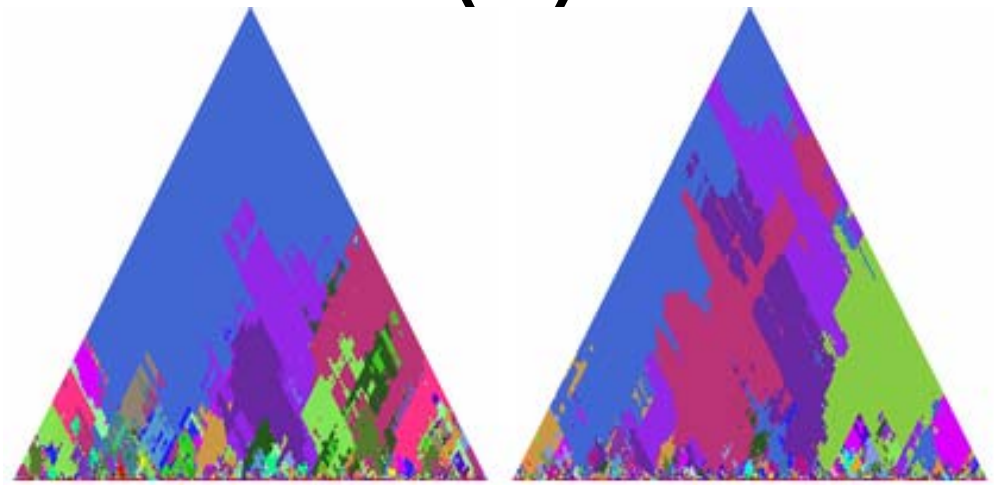
Tempo only

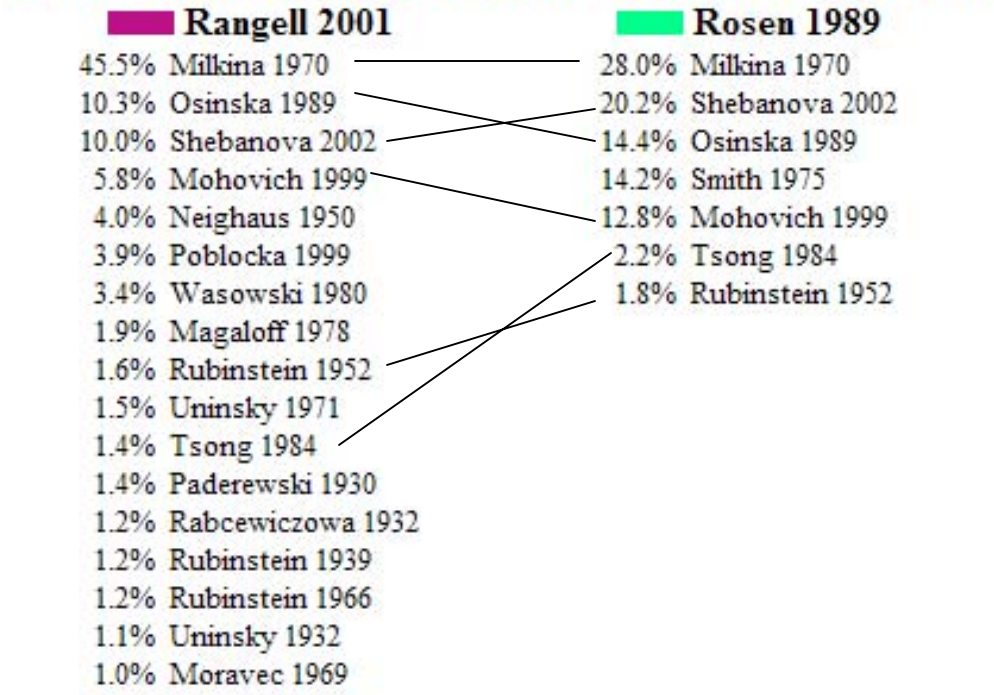
Rangell 2001

45.5% Milkina 1970
10.3% Osinska 1989
10.0% Shebanova 2002
5.8% Mohovich 1999
4.0% Neighaus 1950
3.9% Poblocka 1999
3.4% Wasowski 1980
1.9% Magaloff 1978
1.6% Rubinstein 1952
1.5% Uninsky 1971
1.4% Tsong 1984
1.4% Paderewski 1930
1.2% Rabcewiczowa 1932
1.2% Rubinstein 1939
1.2% Rubinstein 1966
1.1% Uninsky 1932
1.0% Moravec 1969

Dynamics only

Tempo & Dyanmics: Rangell (2)





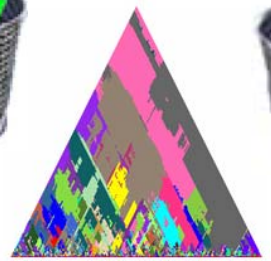
Peeling layers of the Onion

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



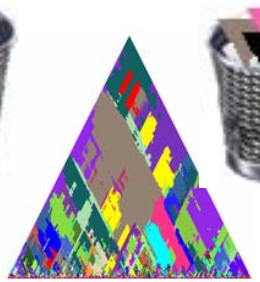
Indjic 1988
19.3% Gierzod 1998
19.2% Uninsky 1971
16.1% Fliere 1977
6.5% Friedman 1923
4.4% Osinska 1989
3.8% Rubinstein 1966
3.3% Poblocka 1999
2.6% Czerny 1949
2.6% Boshniakovich 1969
2.4% Biret 1990
2.2% Ferenczy 1958
1.9% Smith 1975
1.8% Harasiewicz 1955
1.2% Rachmaninoff 1923
1.1% Magaloff 1978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

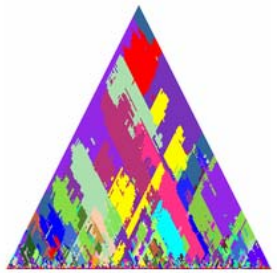
remove Uninsky



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

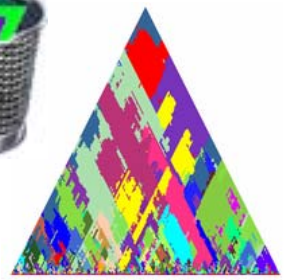
remove Friedman

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



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

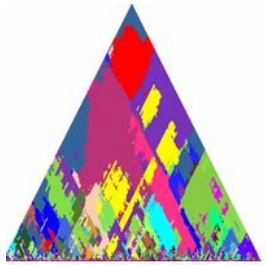
remove Osinksa



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

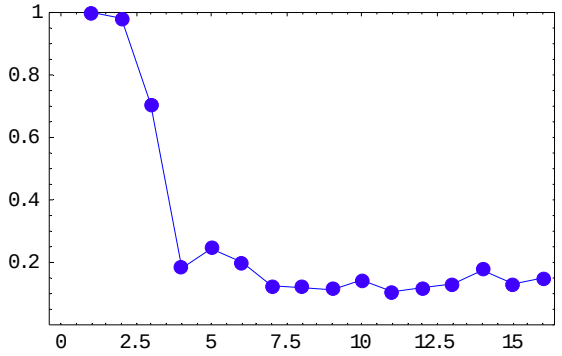


Indjic 1988
16.9% Shebanova 2002
9.9% Schilhawsky 1960
9.6% Harasiewicz 1955
8.2% Boshniakovich 1969
6.6% Afanassiev 2001
6.4% Smith 1975
6.0% Rubinstein 1966
5.6% Poblocka 1999
2.9% Ferenczy 1958
2.8% Friedman 1930
2.6% Biret 1990
2.4% Rachmaninoff 1923
2.2% Neighaus 1950
1.8% Magaloff 1978
1.8% Zak 1937
1.6% Milkina 1970
1.4% Rosen 1989
1.4% Kissin 1993
1.0% Wasowski 1980
1.0% Falvay 1989

Scape Rank

Indjic 1988:

	0. Indjic 1988:	100.0%	* 59/59	**= 1.00**
	1. Hatto 1997:	99.7%	* 58/59	**= .979**
	2. Average:	73.2%	* 57/59	**= .707**
P	3. Gierzod 1998:	19.3%	* 56/59	**= .183**
R	4. Fliere 1977:	26.6%	* 55/59	**= .247**
R	5. Uninsky 1971:	21.9%	* 54/59	**= .200**
P	6. Friedman 1923:	13.8%	* 53/59	**= .124**
P	7. Osinska 1989:	13.9%	* 52/59	**= .122**
P	8. Czerny-Stefanska 1949:	13.4%	* 51/59	**= .115**
P	9. Shebanova 2002:	16.9%	* 50/59	**= .142**
P	10. Harasiewicz 1955:	12.6%	* 49/59	**= .105**
R	11. Boshniakovich 1969:	14.6%	* 48/59	**= .119**
A	12. Schilhawsky 1960:	16.7%	* 47/59	**= .132**
R	13. Afanassiev 2001:	22.8%	* 46/59	**= .178**
R	14. Neighaus 1950:	17.3%	* 45/59	**= .132**
P	15. Friedman 1930:	20.0%	* 44/59	**= .149**
P	16. Poblocka 1999:	14.1%	* 43/59	**= .103**



In the future: scape-rank performance maps…

Observations

- **Recordings have a strong influence on mazurka performance practice.**
  - Internationalization

- **Pianists maintain a stable performance tempo structure over long career.**
  - Rubinstein
  - Uninsky
  - Ts'ong
  - Friedman
  - Horowitz
  - Cortot

c.f. Bruno Repp

- **Like Per Dahl's observations: pianists getting closer to the "average"**
  - also slowing down over time.

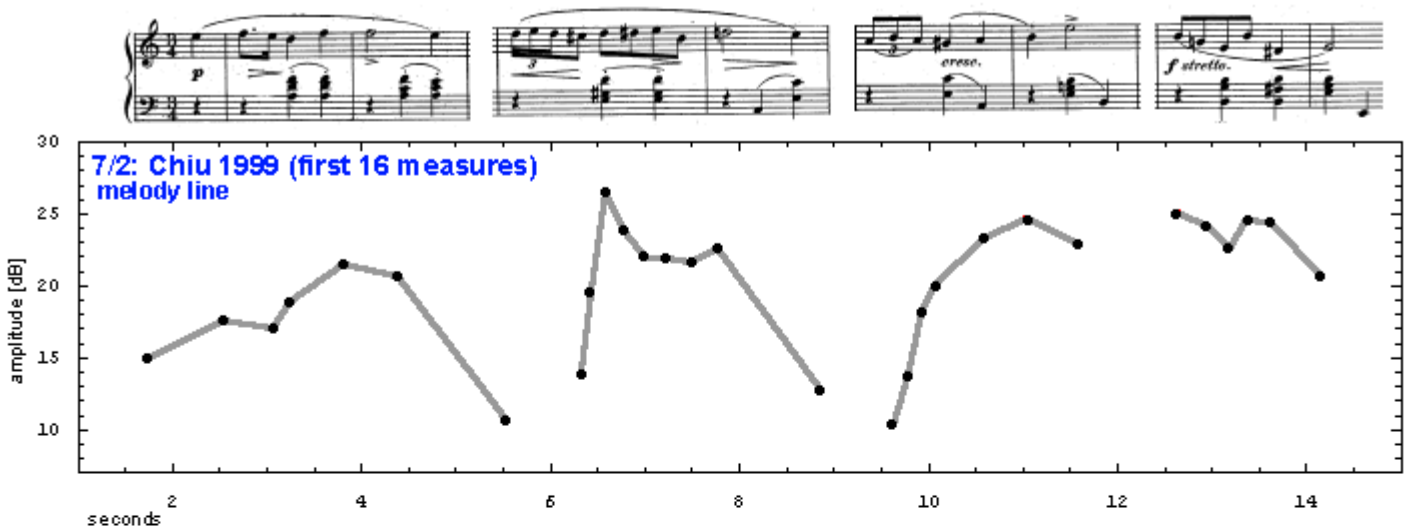
- **Like Daniel Barolsky's observations: dynamics more variable than timing.**

Slides online:

http://mazurka.org.uk/info/present/charm-20070413

Extra Slides

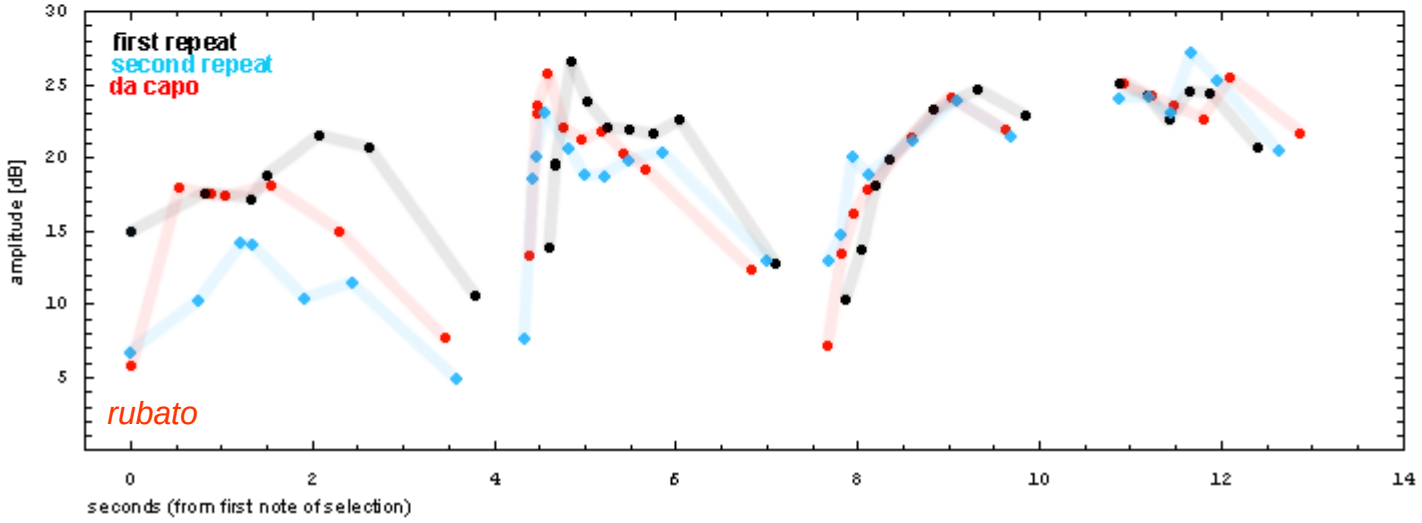
Dynamics & Phrasing



1 

2 

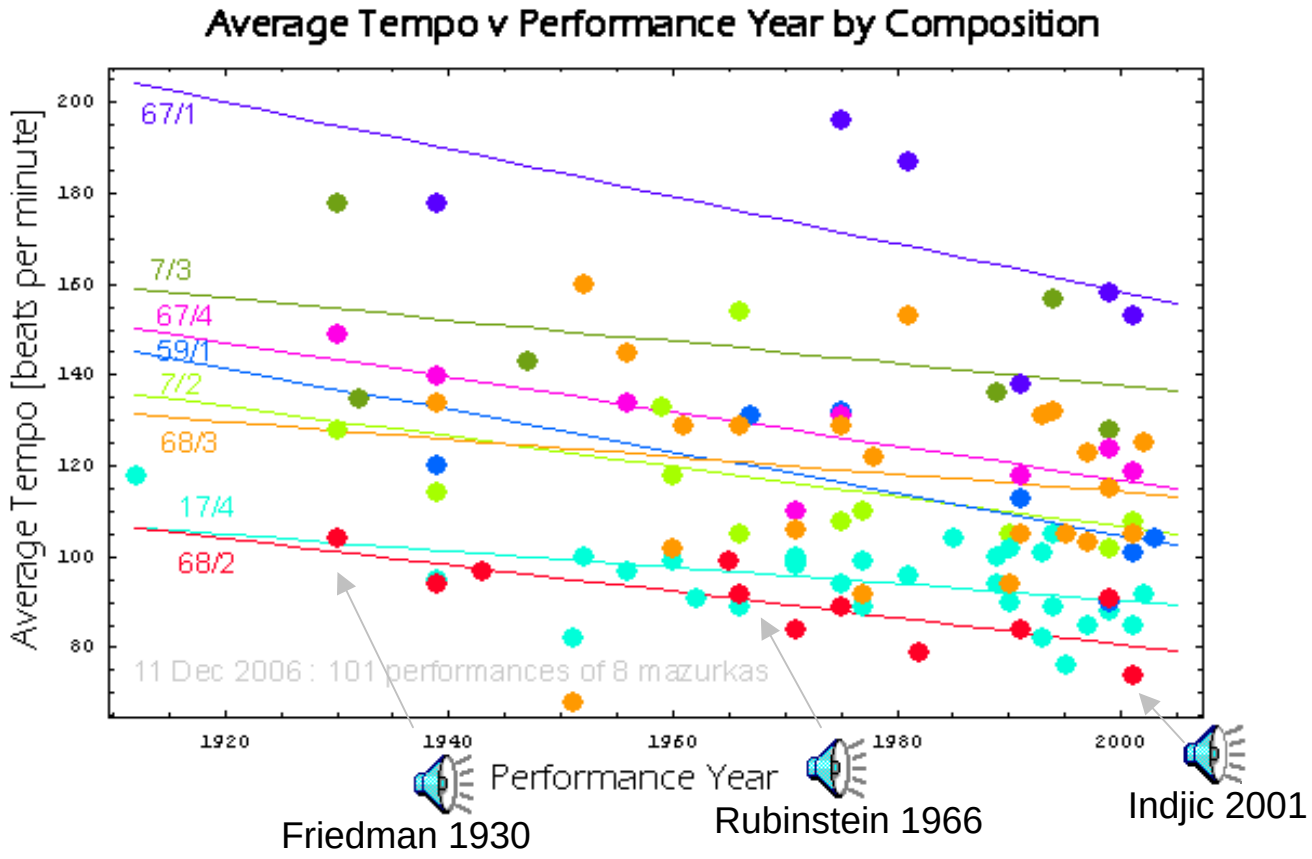
3 



all at once:

Average tempo over time

- Performances of mazurkas slowing down over time:

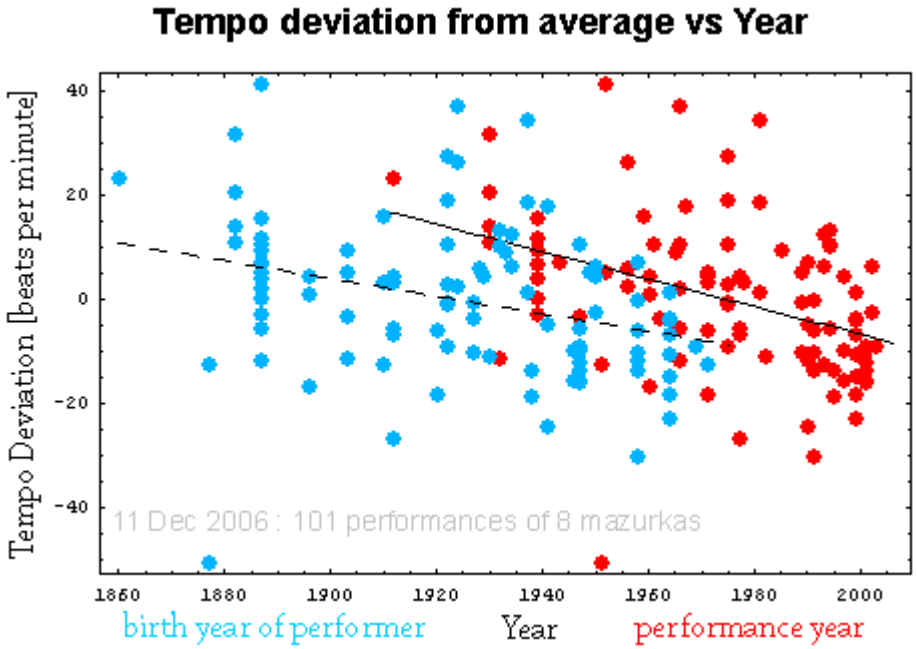


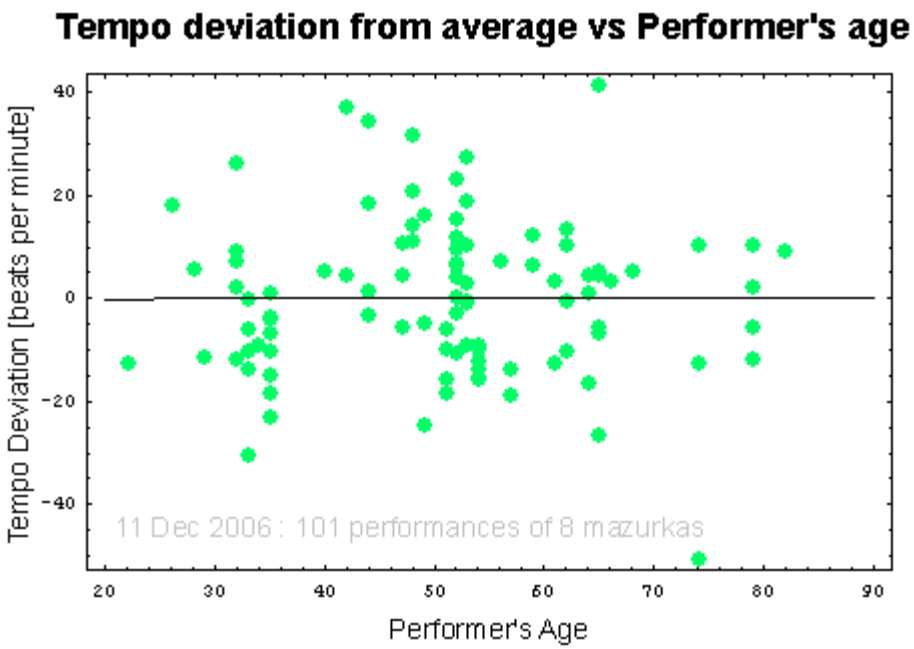
- Slowing down at about 3 BPM/decade

Laurence Picken, 1967: “Centeral Asian tunes in the Gagaku tradition” in *Festschrift für Walter Wiora*. Kassel: Bärenreiter, 545-51.

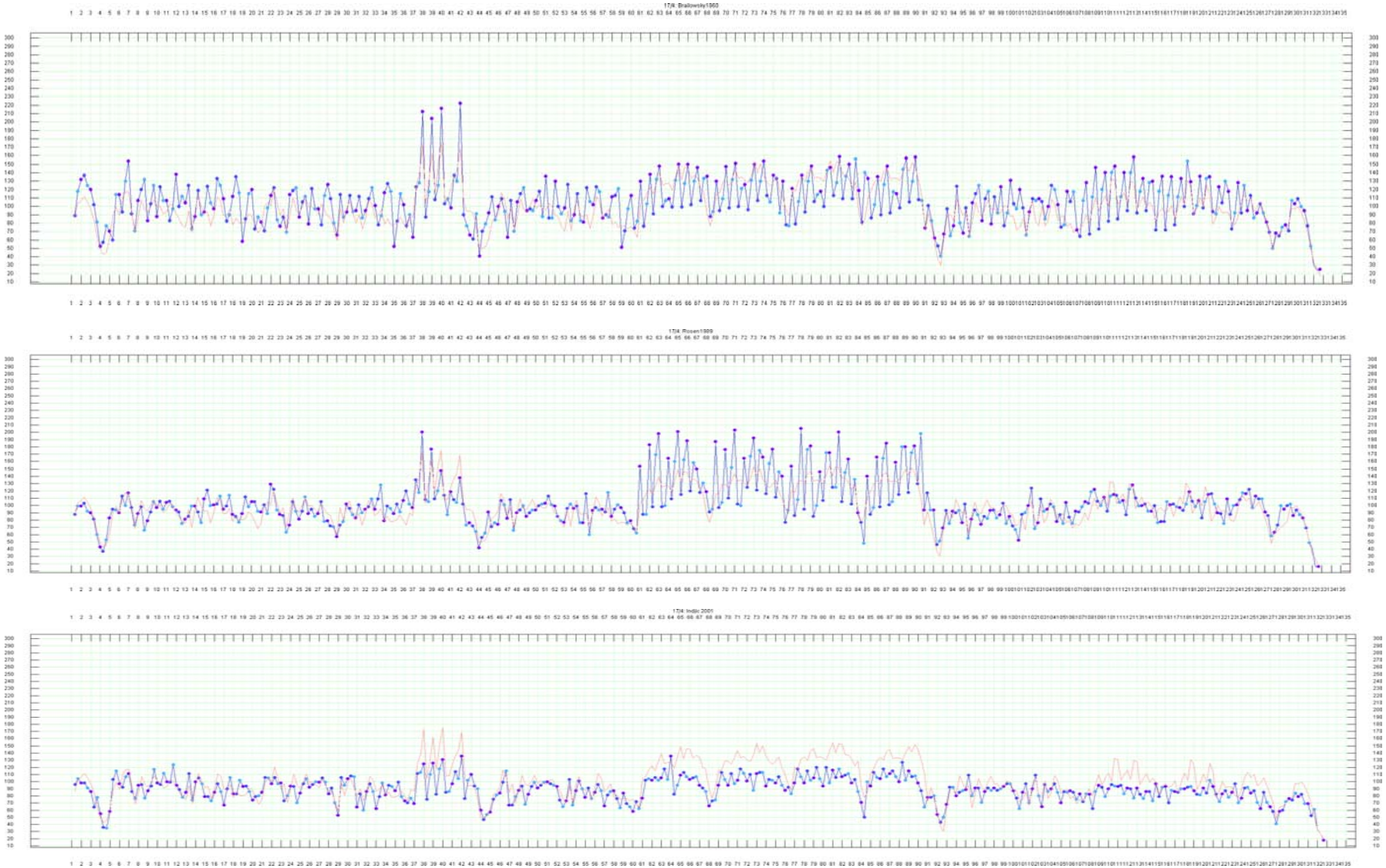
Average Tempo over time (2)

- **The slow-down in performance tempos is unrelated to the age of the performer**





Tempo graphs

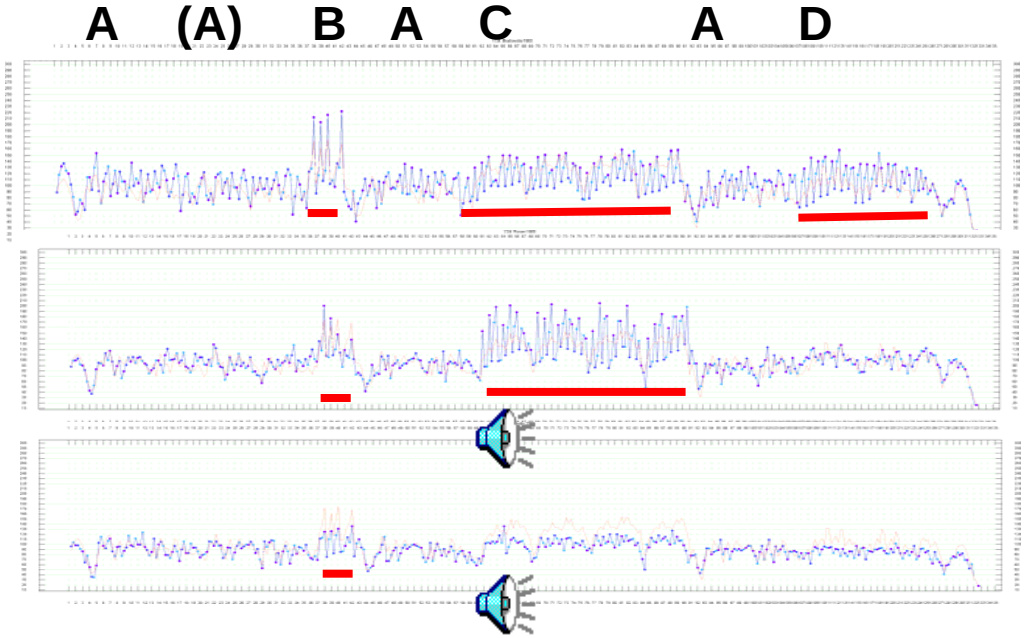


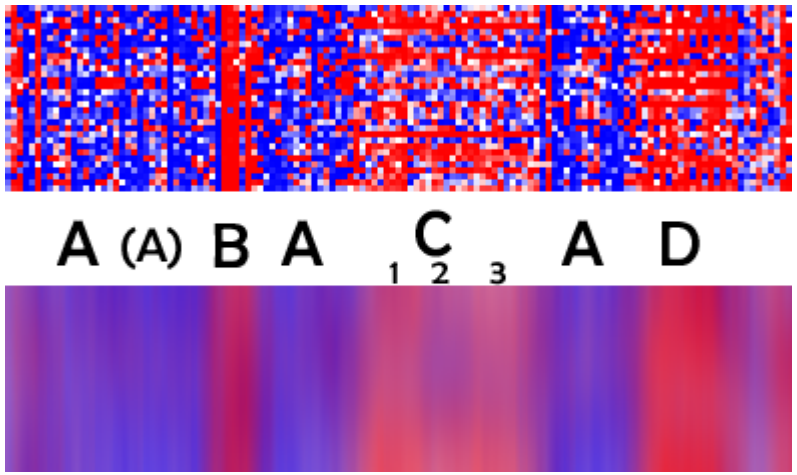
http://mazurka.org.uk/ana/tempograph

Mazurka Meter

- **Stereotypical mazurka rhythm:**
  - **First beat short**
  - **Second beat long**

Mazurka in A minor
Op. 17, No. 4

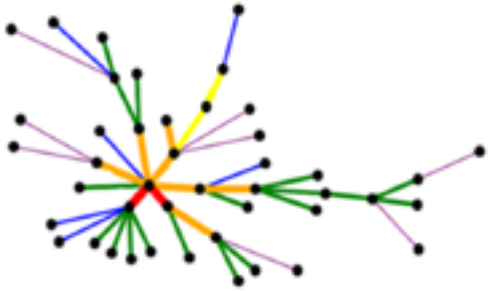




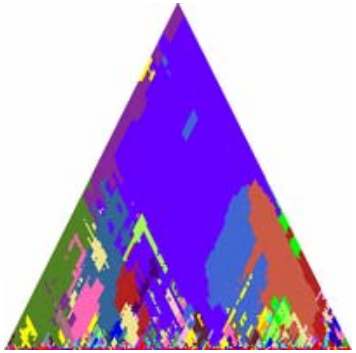
measure with longer second beat
measure with longer first beat

- blurred image to show overall structure

Maps and scapes

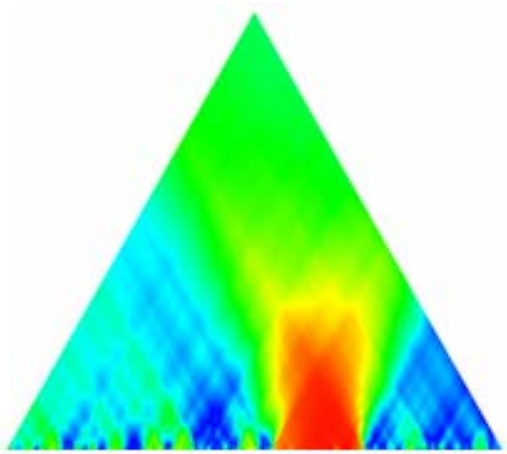


Correlation maps give gross detail, like a real map:

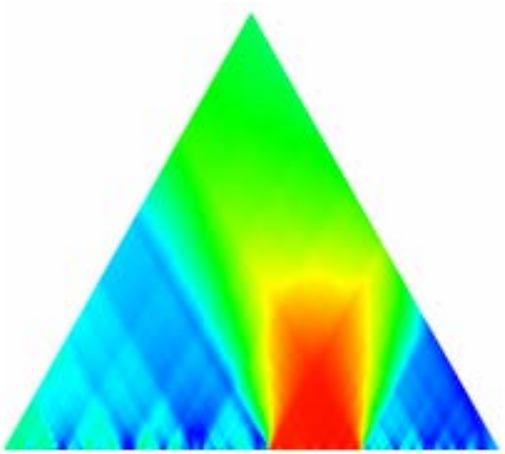


Correlation scapes give local details, like a photograph:

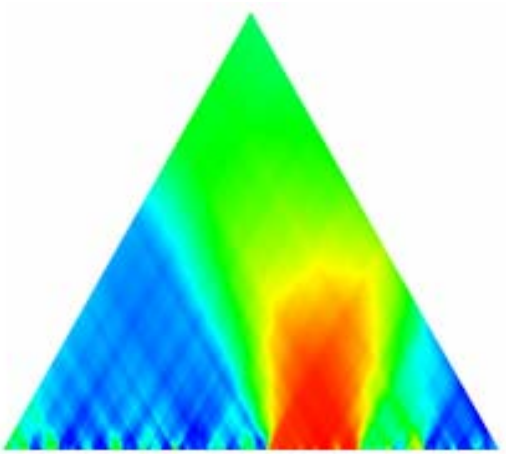
Comparison of performers



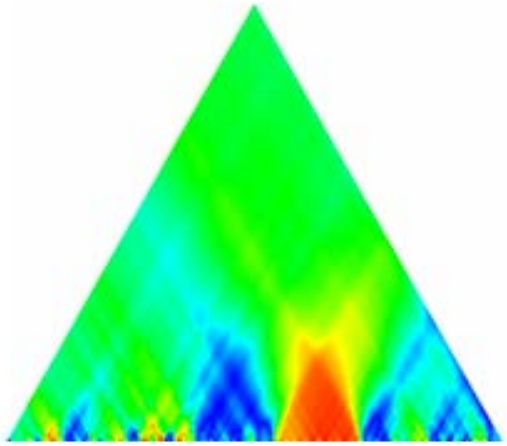
Chiu 1999



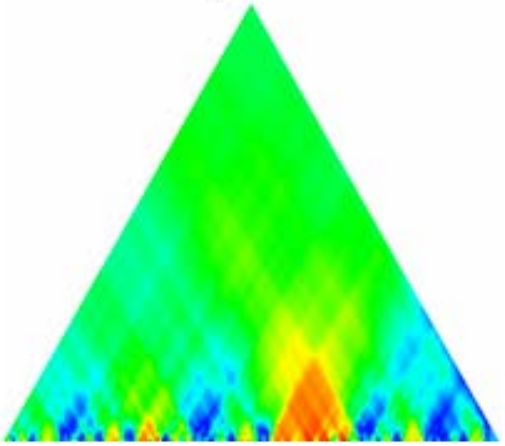
Indjic 2001



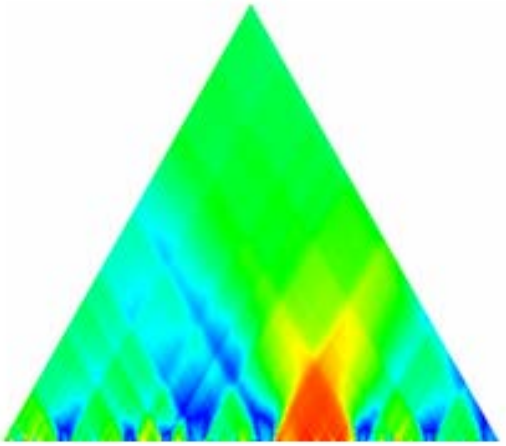
Luisada 1991



Rubinstein 1938

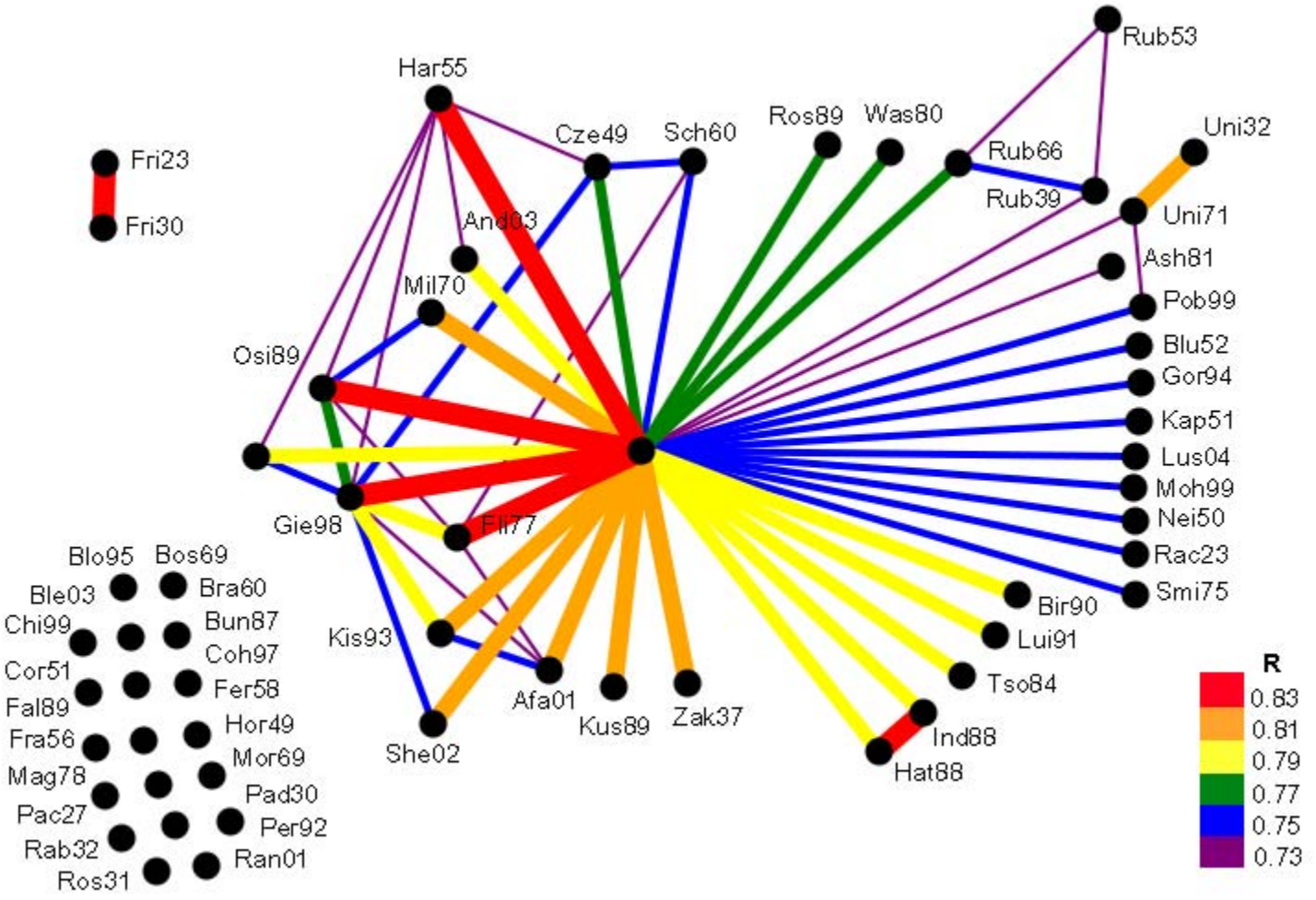


Rubinstein 1961

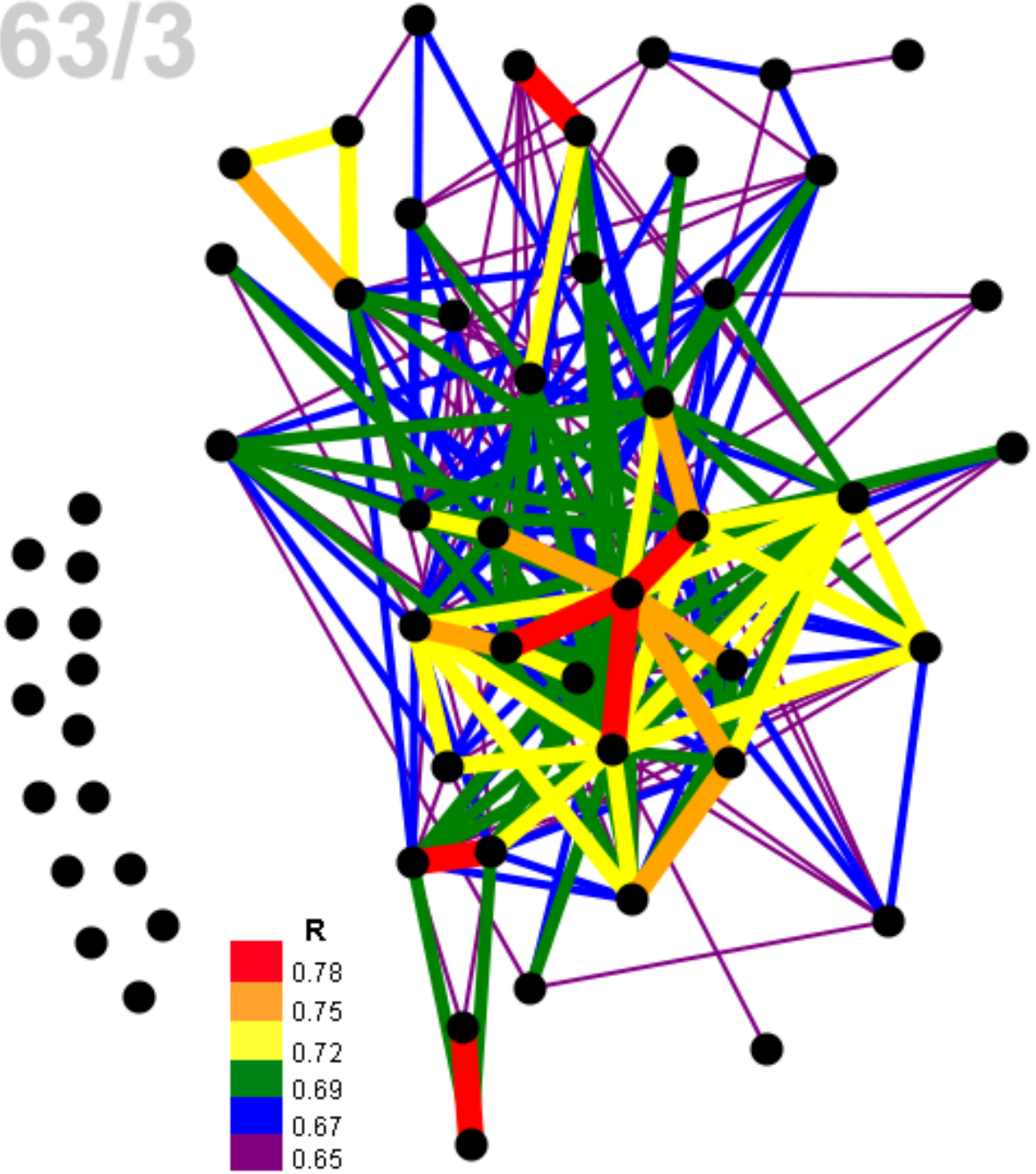


Smith 1975

Absolute Correlation Map

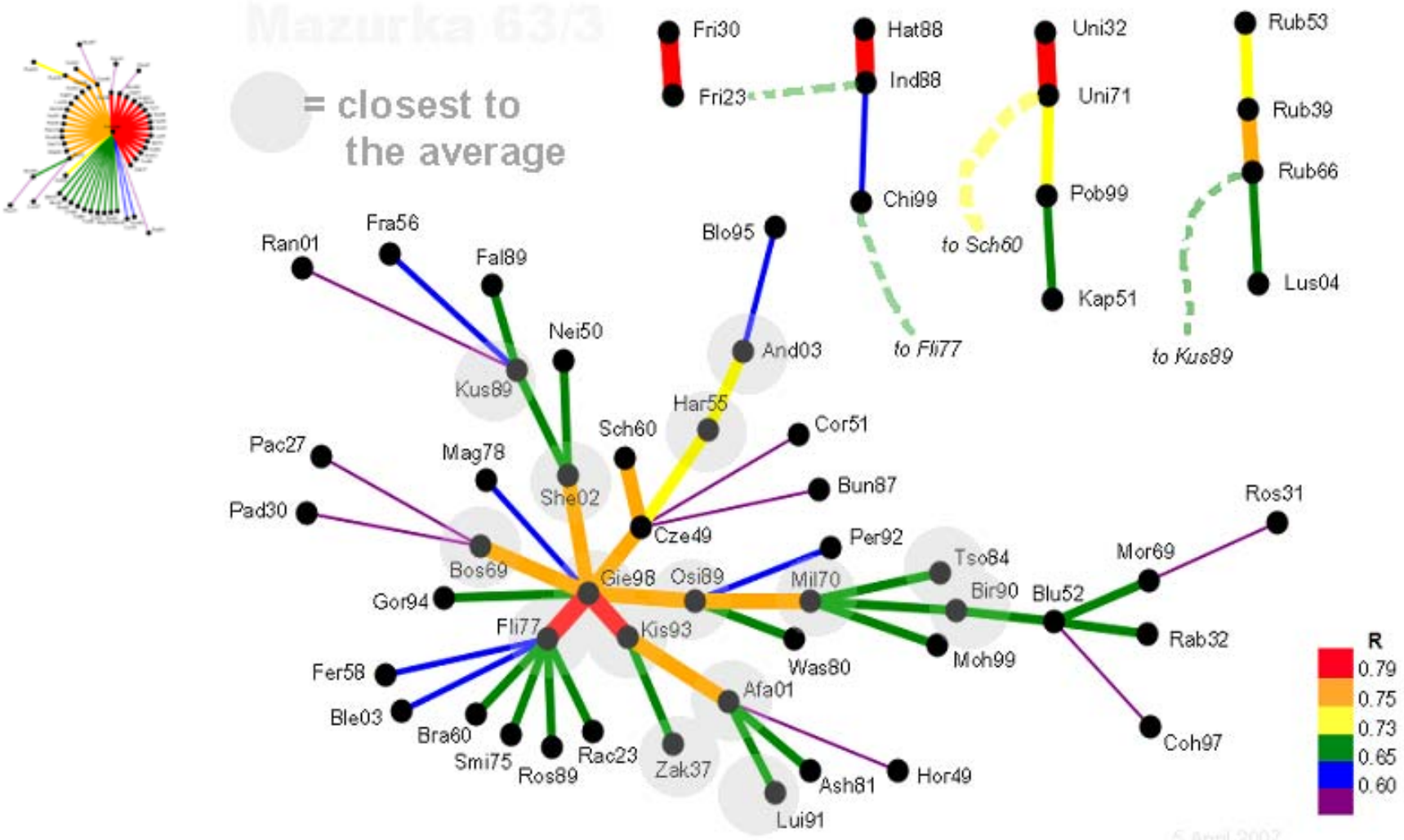


Absolute correlation without average

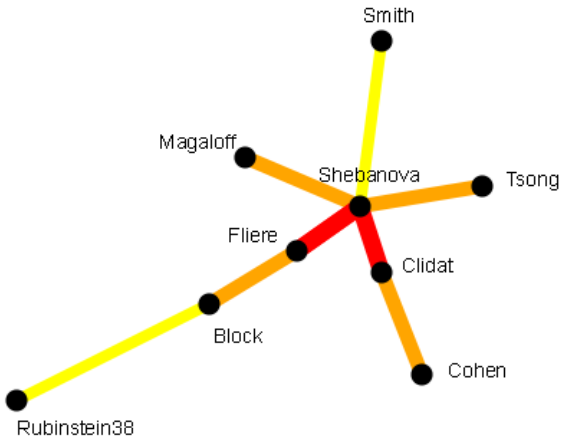


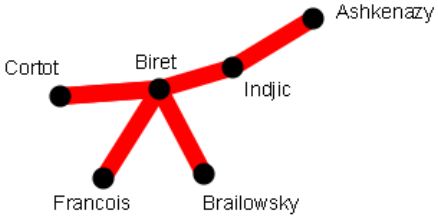
- Correlation maps are showing best correlations for *entire* performances

Closeness to the average

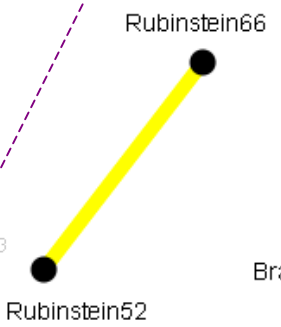


Correlation trees

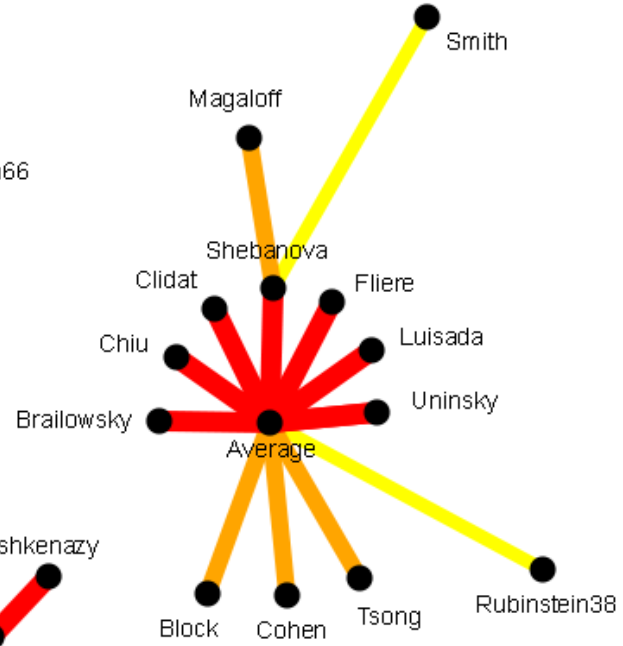


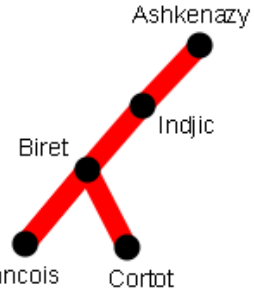


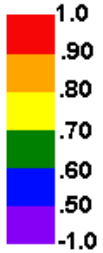
Mazurka 68/3



Mazurka in A minor, 68/3

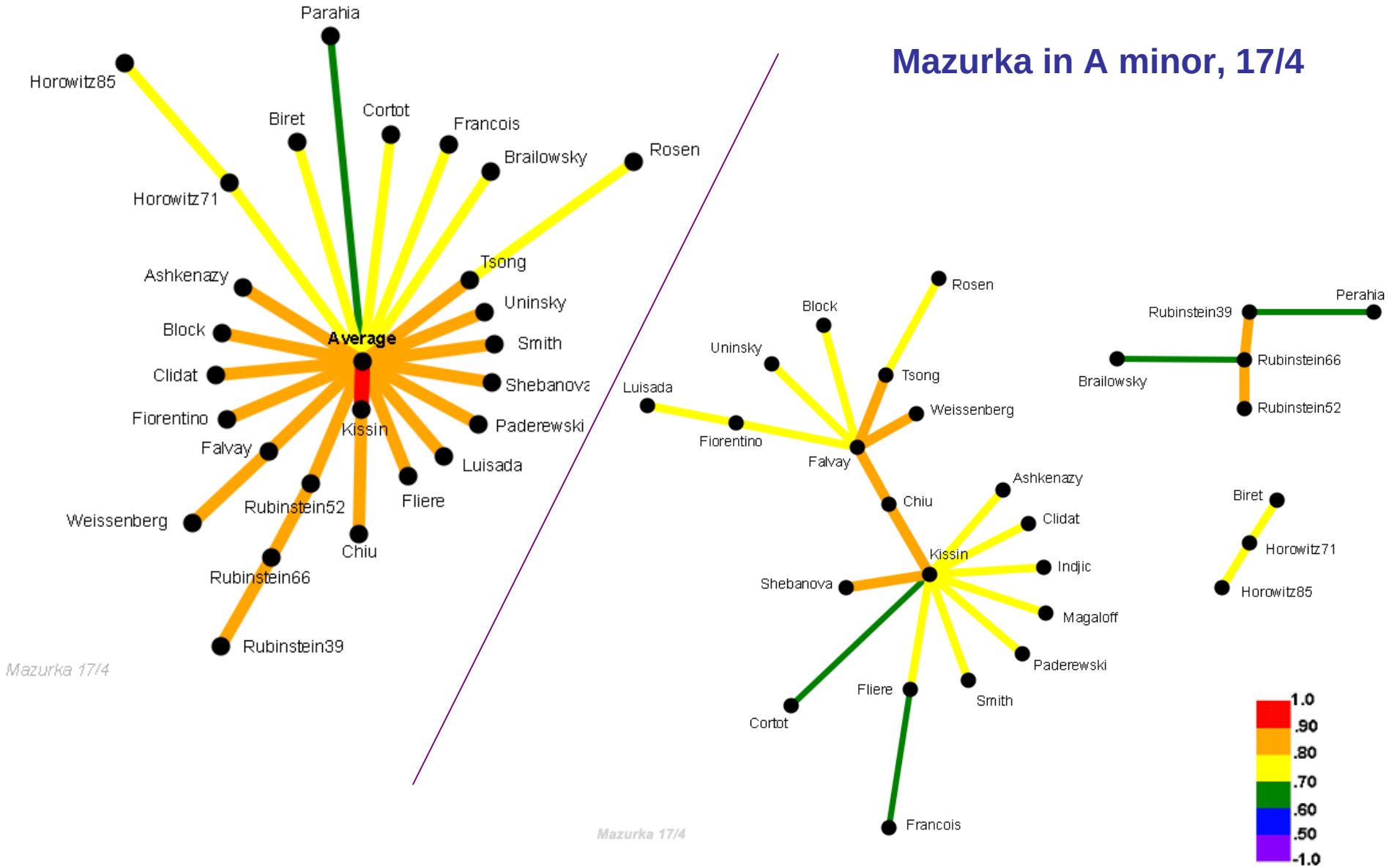






Mazurka 68/3

Correlation tree

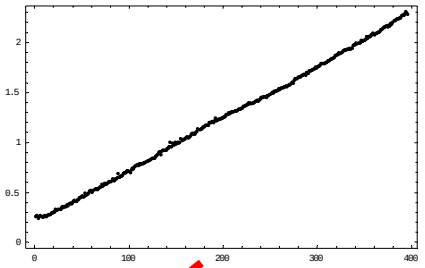


Beat-Event Timing Differences

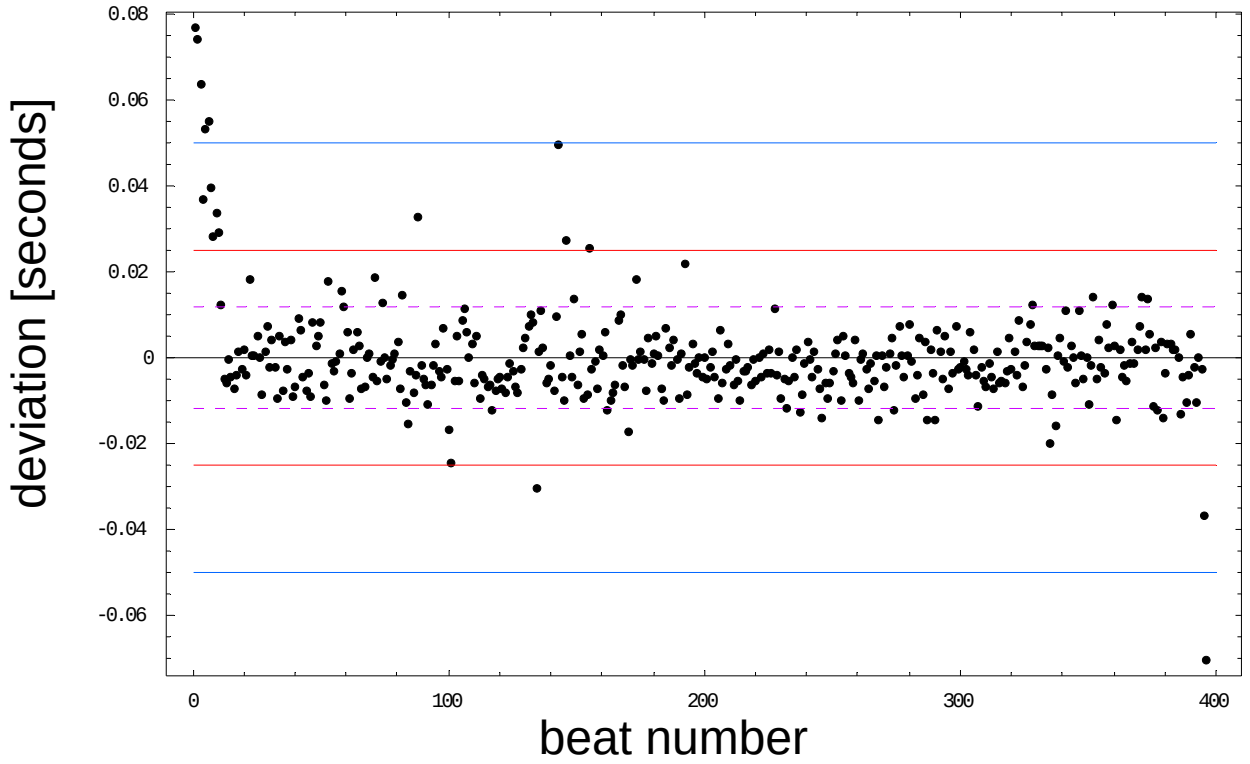
Hatto beat location times: 0.853, 1.475, 2.049, 2.647, 3.278, etc.

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

difference plot

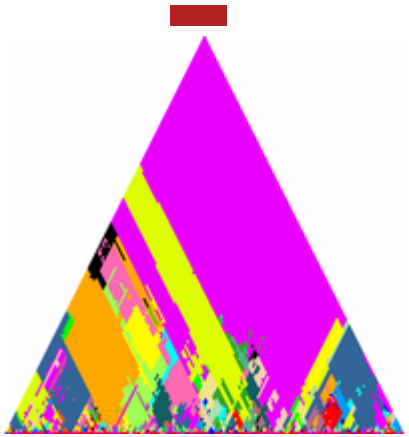


Hatto / Indjic beat time deviations



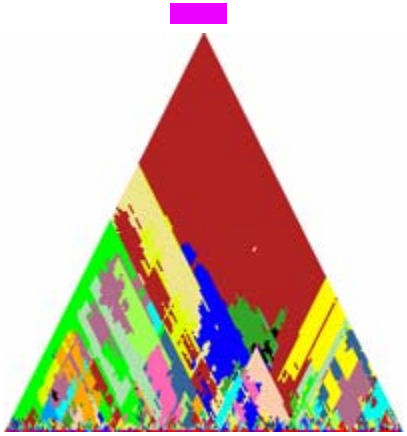
remove 0.7% timeshift

The conspiracy goes deeper? or Not?



f

c



b

How time + dynamics are mixed

Correlation:

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

t_n = (t1, t2, t3, t4, t5, t6, t7, t8, …, tn) ***original tempo sequence***

d_n = (d1, d2, d3, d4, d5, d6, d7, … dn) ***original dynamic sequence***

J_n = (Jt1, Jd1, Jt2, Jd2, Jt3, Jd3, …, Jtn, Jdn) ***joint sequence***

original time sequence is unaltered:

$$J_{t,n} = t_n$$

original dynamic sequence is scaled to match tempo sequence's mean and standard deviation:

$$J_{d,n} = \sigma_t \left(\frac{d_n - \mu_d}{\sigma_d} \right) + \mu_t$$

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2}$$