The Mazurka Project

CHARM Symposium
Kings College London
6 January 2006

Recent Progress

- **Collected about 400 performances of mazurkas on 34 CDs**

- **Rough score alignment by tapping to recording**

  For human-assisted alignment of performances to score

- **Basic evaluation of tapping quality**

  How accurate is reverse conducting? / Quality metrics

- **Raw input to automated alignment process**

  Andrew will present current state of automatic alignment

- **Website for data and analysis results:**

  `http://mazurka.org.uk`

Sample Performance Listing

		Duration	*Performer (year)*	*Label*
Mazurka in A minor	Op. 17, No. 4	4:36	Chiu (1999)	HMX 2907352.53
		4:03	Horowitz (1971)	S3K 93039 Legacy
		4:00	Horowitz (1985)	DG 419 045-2
		4:48	Indjic (2001)	Calliope 3321
		4:00	Luisada (1990)	DG 463054-2
		4:05	Magaloff (1977)	Philips 456 898-2
		3:23	Paderewski (1912)	Philips 456 919-2
		4:30	Perahia (1994)	Sony 45931
		4:20	Rosen (1989)	Globe 5028
		4:16	Rubinstein (1939)	Naxos 8.110656-57
		3:41	Rummel (1943)	Dante HPC027
		2:15	Smith (1975)	EMI 724358576726

Full list of collected performances at:

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

Reverse Conducting and Score Alignment

Lots of Tapping

- Reverse conducting of same performance 20 times
  - used to smooth out errors in individual sessions
  - used to test various automatic windowing methods (such as SD)
  - takes about 3 hours / performance to record and process 20 trials

    So 2 performances can be tapped per day
  - about 400 performances of the mazurkas collected
  - 20 performances have been reverse conducted thus far:

    7 performances of Op. 7, No. 2 in A Minor
    6 performances of Op. 7, No. 3 in F Minor (initial test case)
    7 performances of Op. 17, No. 4 in A Minor

Data Entry Method

- **`backbeat.exe`: command-line program for recording tap times**

- Absolute time from first click in milliseconds.

- Other 3 fields for error checking (during performance and afterwards).

- Computer keyboard resolution is 5 milliseconds.

Space bar records beats

Any letter records barline and first beat of measure

Example output:

Beat duration (quarter note)	*Metric position*	*Absolute Time (ms)*	*Delta Time (ms)*	
**kern	**beat	**abstm	**deltatime	
=1-	=1-	=1-	=1-	
4	1	0	0	
4	2	391	391	
4	3	741	350	
=2	=2	=2	=2	
4	1	1080	339	
4	2	1454	374	
4	3	1807	353	
=3	=3	=3	=3	
4	1	2108	301	
4	2	2448	340	
4	3	2785	337	
=4	=4	=4	=4	← *barline*
4	1	3108	323	
4	2	3472	364	
4	3	3812	340	

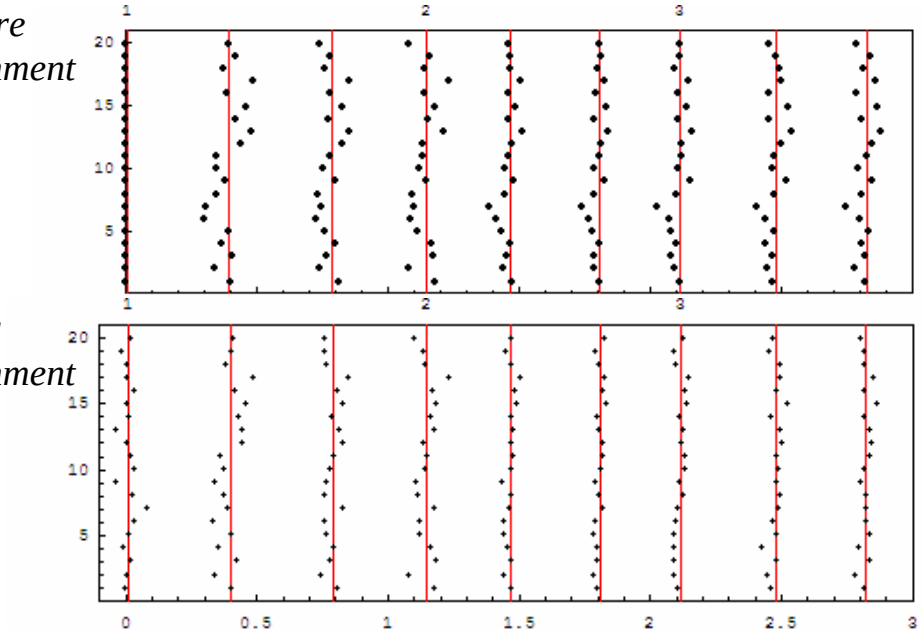
`http://mazurka.org.uk/info/revcond`

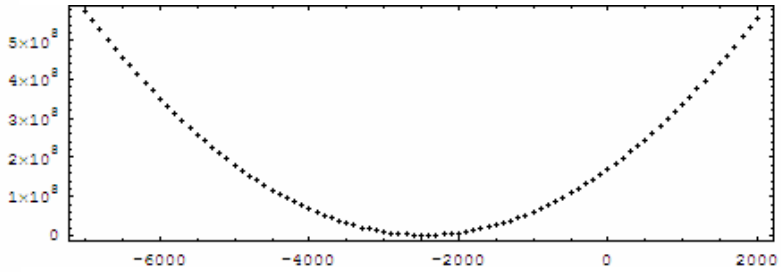
Offset Alignment with Audio

- Need to align first tap to first note in recording.
- Cannot just measure start time of note in audio.
- Individual tapping trials aligned by least squares fit to a sample of manually measured beat time in audio file.

Before alignment

After alignment





Typical deviations from correct offset:
5, -12, -27, -36 ms

Examples of final alignment:

Play pid5667230-10-avg (Friedman 1930)

Play pid54293-08-avg (Perahia 1994)

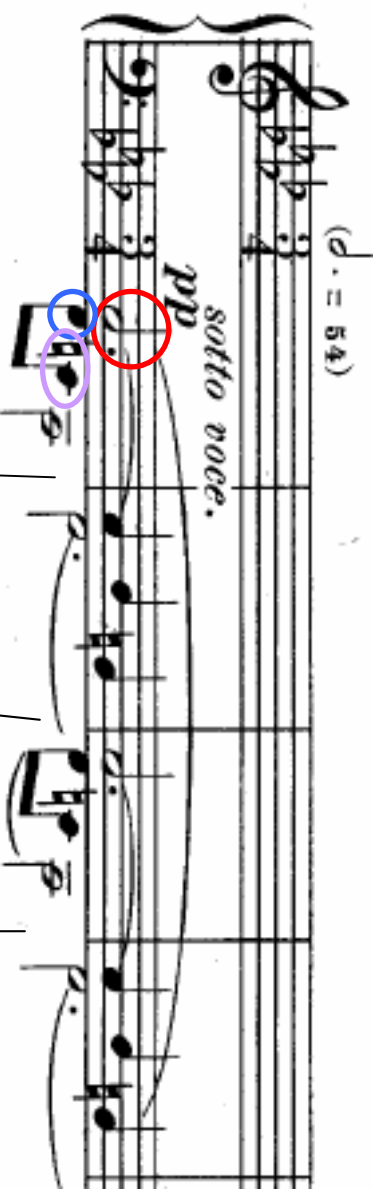
Tapping Summary Data

**kern	**beat	**time	**dur	**min	**max	**cmin	**cmax	**sd
4	3	2177	474.95	1935	2265	2147	2206	63.5
=1	=1	=1	=1	=1	=1	=1	=1	=1
4	1	2652	389.1	2536	2832	2624	2679	59.1
4	2	3041	400.15	2921	3137	3017	3065	51.7
4	3	3441	451.65	3399	3493	3429	3453	25.7
=2	=2	=2	=2	=2	=2	=2	=2	=2
4	1	3893	361.85	3845	3957	3879	3906	28.8
4	2	4254	460.4	4206	4283	4245	4264	20.7
4	3	4715	416.3	4620	4780	4697	4733	38.9
=3	=3	=3	=3	=3	=3	=3	=3	=3
4	1	5131	353.65	5039	5225	5108	5154	48.6
4	2	5485	362.45	5433	5541	5471	5499	29.8
4	3	5847	355.45	5780	5911	5830	5864	36.5
=4	=4	=4	=4	=4	=4	=4	=4	=4
4	1	6203	363.7	6160	6266	6189	6216	28.2
4	2	6566	490.25	6490	6602	6552	6580	29.9
4	3	7057	368.2	6980	7154	7036	7077	43.1
=5	=5	=5	=5	=5	=5	=5	=5	=5
4	1	7425	279.65	7318	7478	7407	7443	38.4
4	2	7704	397.85	7657	7760	7693	7716	24.1
4	3	8102	426.65	8058	8160	8089	8115	27.6

Score Alignment and Time Interpolation

Abs times **Score**

**time	**kern		**kern
=1-	=1-		=1-
*	*^		*
2465	([2.C/	8FF\L	2.r
2659	.	8EEn\J	.
2852	.	2CC\	.
3243	.	.	.
=2	=2	=2	=2
3604	4C/]	[2.FF\	2.r
3921	4D-/	.	.
4261	4BBn/	.	.
=3	=3	=3	=3
4569	[2.C/	8FF\L]	2.r
4759	.	8EEn\J	.
4935	.	2CC\	.
5279	.	.	.
=4	=4	=4	=4
5604	4C/]	[2.FF\	2.r
5928	4D-/	.	.
6291	4BBn/)	.	.
=5	=5	=5	=5



Output data to Matlab

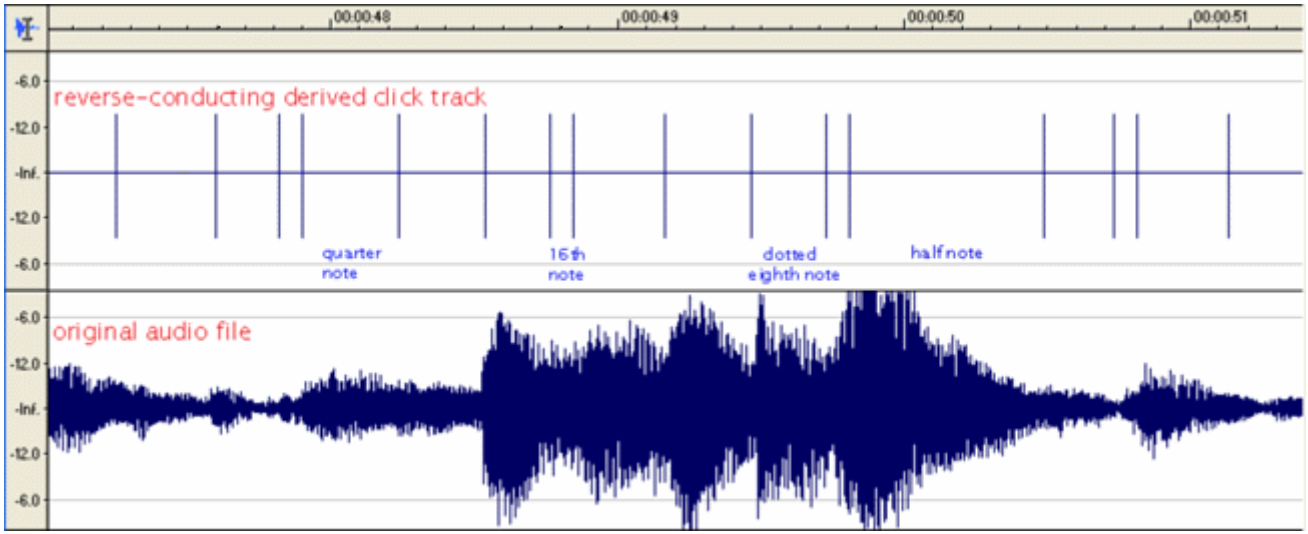
Created from timed score + tapping summary data

%%%col01: **abstime** (average absolute time in milliseconds of human beats)
%%%col02: **duration** (expected duration in ms based on score duration)
%%%col03: **note** (MIDI note number of pitch)
%%%col04: **metlev** (metric level: 1 = downbeat; 0 = beat; -1 = offbeat)
%%%col05: **measure** (measure number in which note occurs)
%%%col06: **absbeat** (absolute beat from starting beat at 0)
%%%col07: **mintime** (minimum absolute time of human beat for this note)
%%%col08: **maxtime** (maximum absolute time of human beat for this note)
%%%col09: **sd** (standard deviation of human beat time in ms.)

2465	1456	48	1	1	0	2419	2535	24.1
2465	194	41	1	1	0	2419	2535	24.1
2659	193	40	-1	1	0.5	-1	-1	-1
2852	752	36	0	1	1	2762	2947	52.4
3604	1155	41	1	2	3	3550	3648	19.8
3921	340	49	0	2	4	3879	3978	26.1
4261	308	47	0	2	5	4239	4275	9.2
4569	1359	48	1	3	6	4548	4585	11.6
4759	176	40	-1	3	6.5	-1	-1	-1
4935	669	36	0	3	7	4906	4968	18.7
5604	1235	41	1	4	9	5585	5628	14.8
5928	363	49	0	4	10	5894	5977	22.2
6291	367	47	0	4	11	6241	6317	15.8
6658	4438	48	1	5	12	6636	6682	13.1
6839	175	40	-1	5	12.5	-1	-1	-1

Tapping Quality Measurements

Manual correction of the beat times



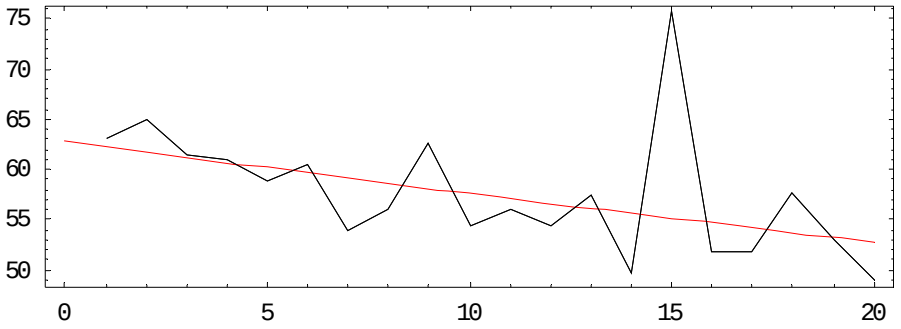
- Align tapped beats within 10 ms by ear/eye in sound editor
- Each beat alignment takes about 1-2 minutes on average
- 300 beats in each mazurka = 1 to 2 days for a performance
- Necessary for evaluation of automatic alignment
- 4 manual corrections done to date (for 7-2 & 7-3)

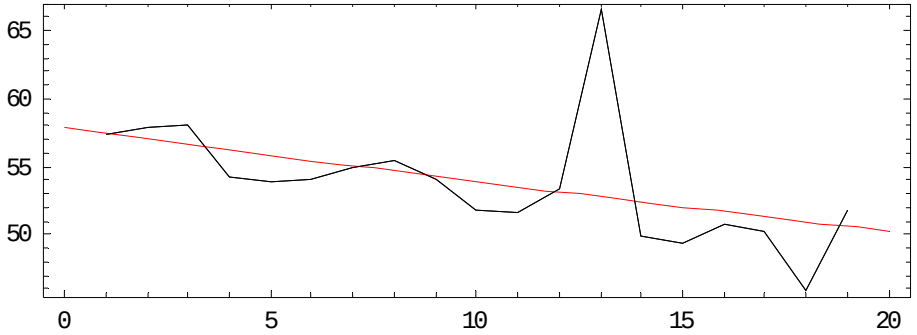
Play pid5667230-10-corr (Friedman 1930)

Learning Curves for 4 Performances

Mazurka in F Minor, Op. 7, No. 3

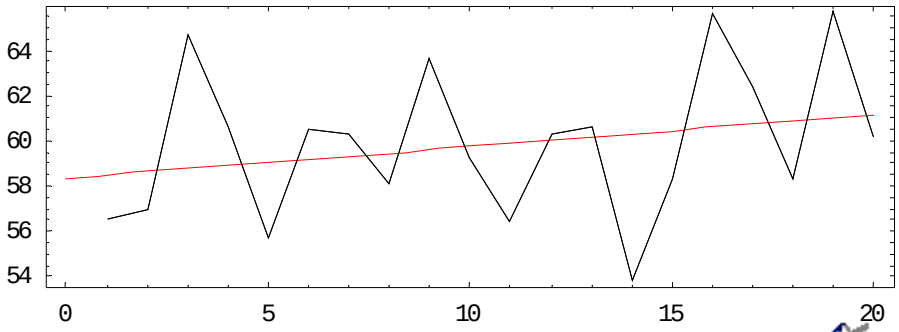
Rosen 1989 **Friedman 1930**

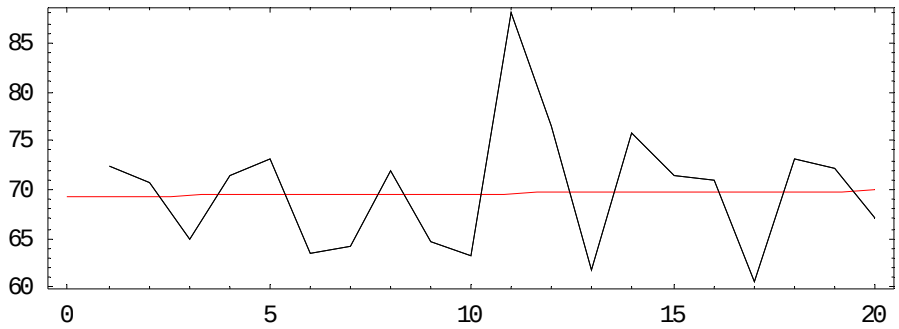




Mazurka in A Minor, Op. 7, No. 2

Chiu 1999 **Friedman 1930**

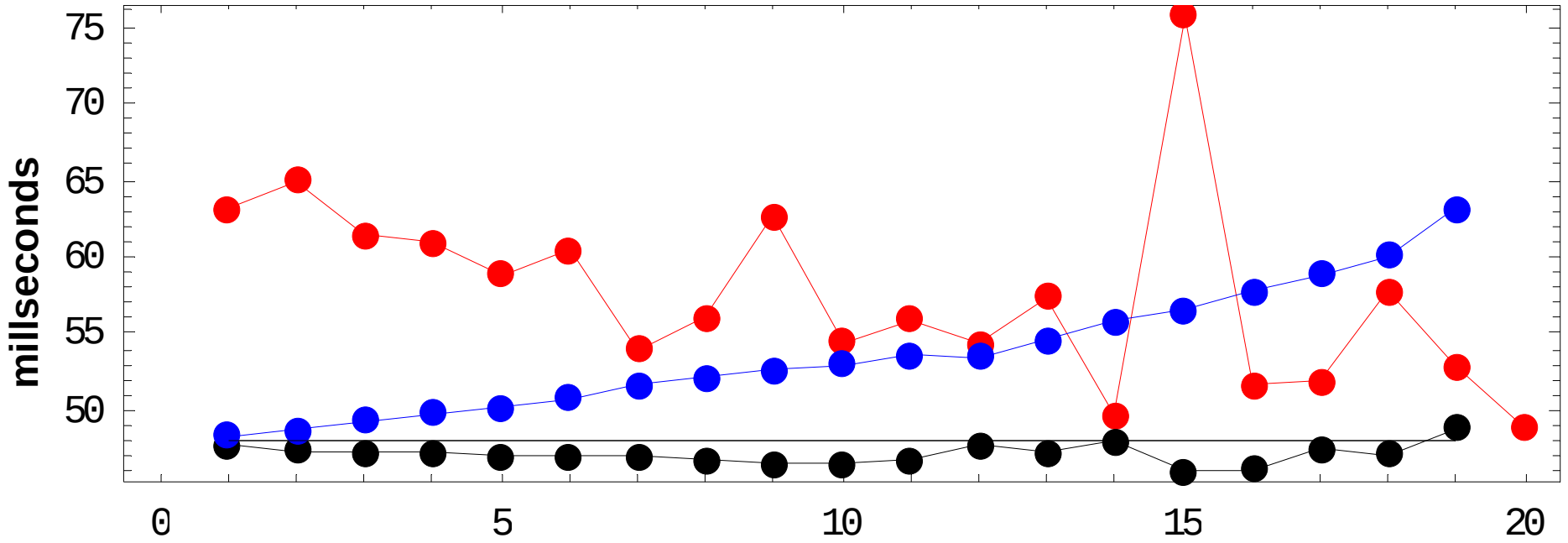




Play pid9048-06-avg (Chiu 1999)

Average Displacement Errors

Mazurka in F Minor, Op. 7, No. 3
Rosen 1989



= individual trial average displacement errors

= dropping more and more later trials

= dropping more and more earlier trials

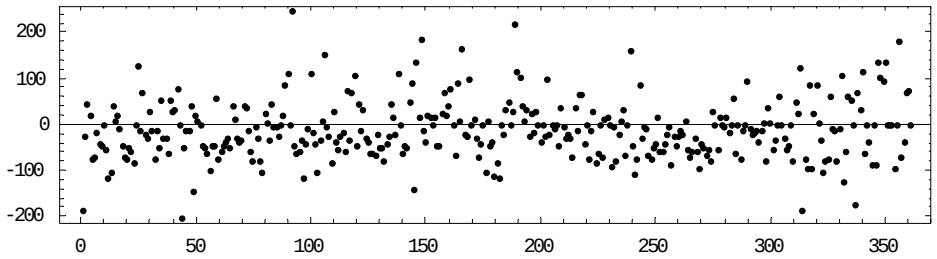
Correction Offsets

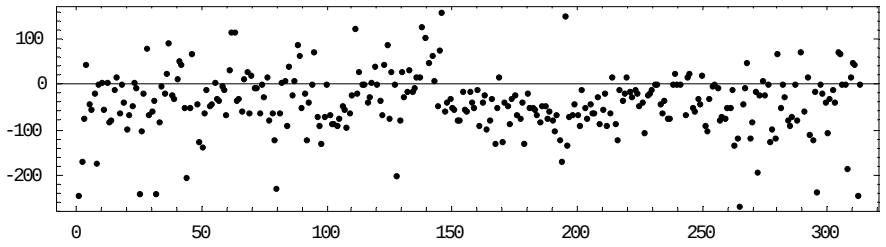
The top plots show amount of time in milliseconds between corrected beat times and average manually tapped beat times. Lower plots display a histogram of same.

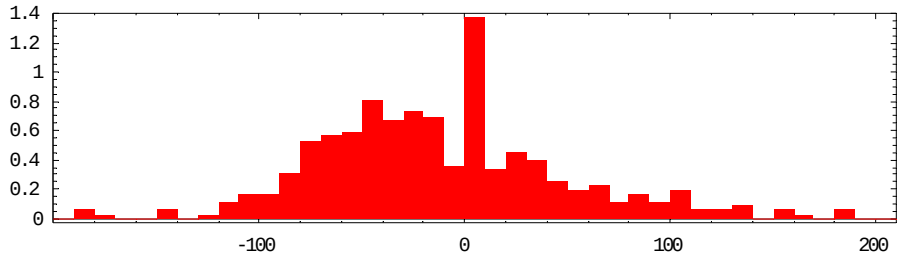
Spike at 0 in histograms due to 10 ms audible corrections resolution.

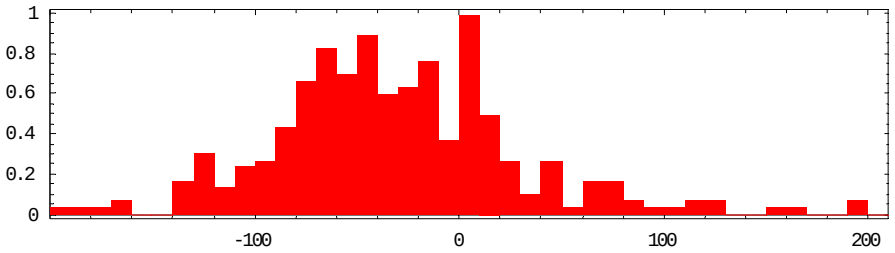
Mazurka in A Minor, Op. 7, No. 2

Chiu 1999 **Friedman 1930**









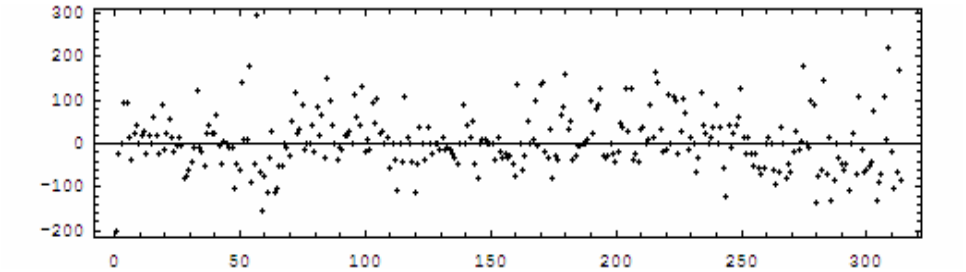
49 ms avg correction; -12 ms overall shift

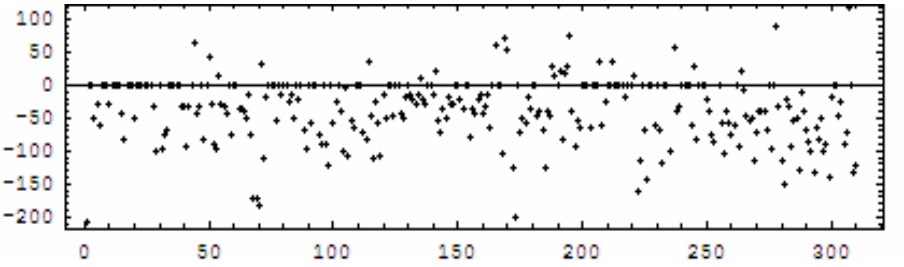
60 ms avg correction; -36 ms overall shift

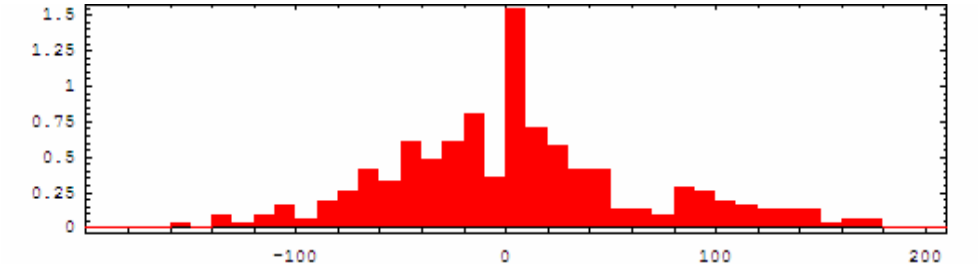
Correction Offsets (2)

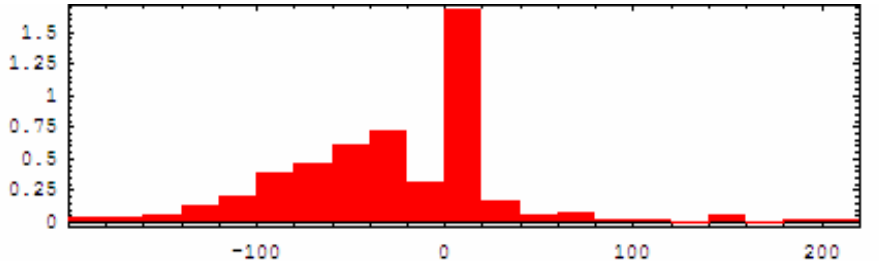
Mazurka in F Minor, Op. 7, No. 3

Rosen 1989 **Friedman 1930**







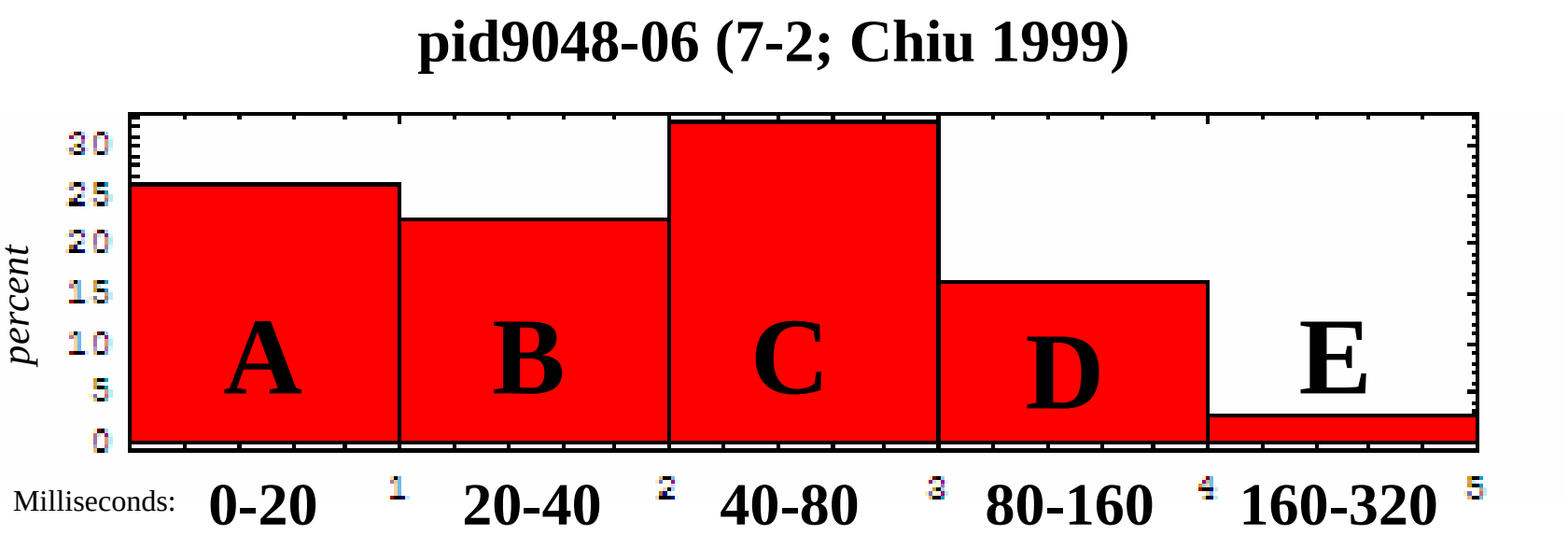


48 ms avg correction; +5 ms overall shift

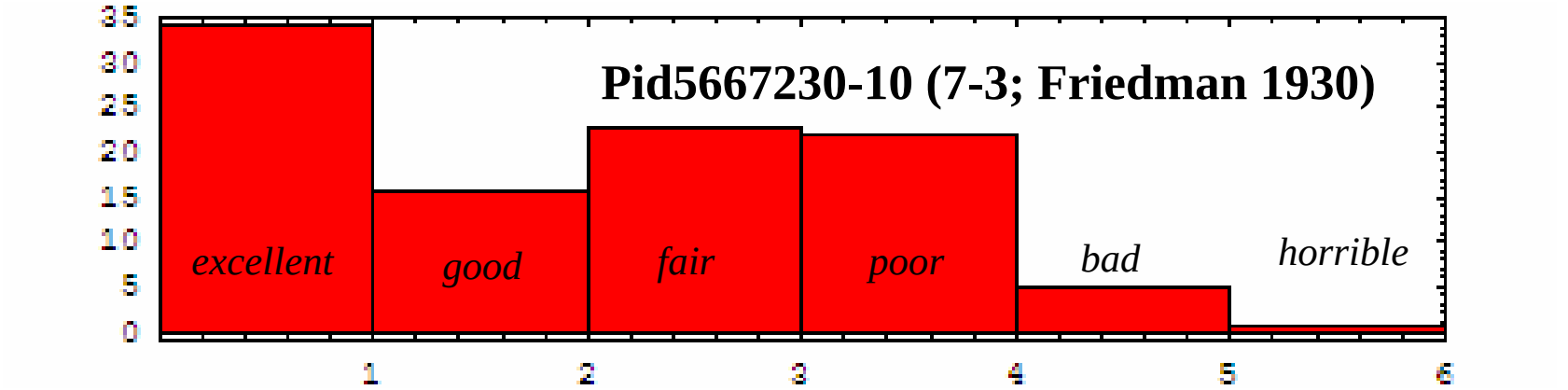
48 ms avg correction; -27 ms overall shift

Beat Accuracy Metric

Logarithmic scale to measure differences between tapped and true beat location:



- Human tapper: 48% of beats within 40 milliseconds

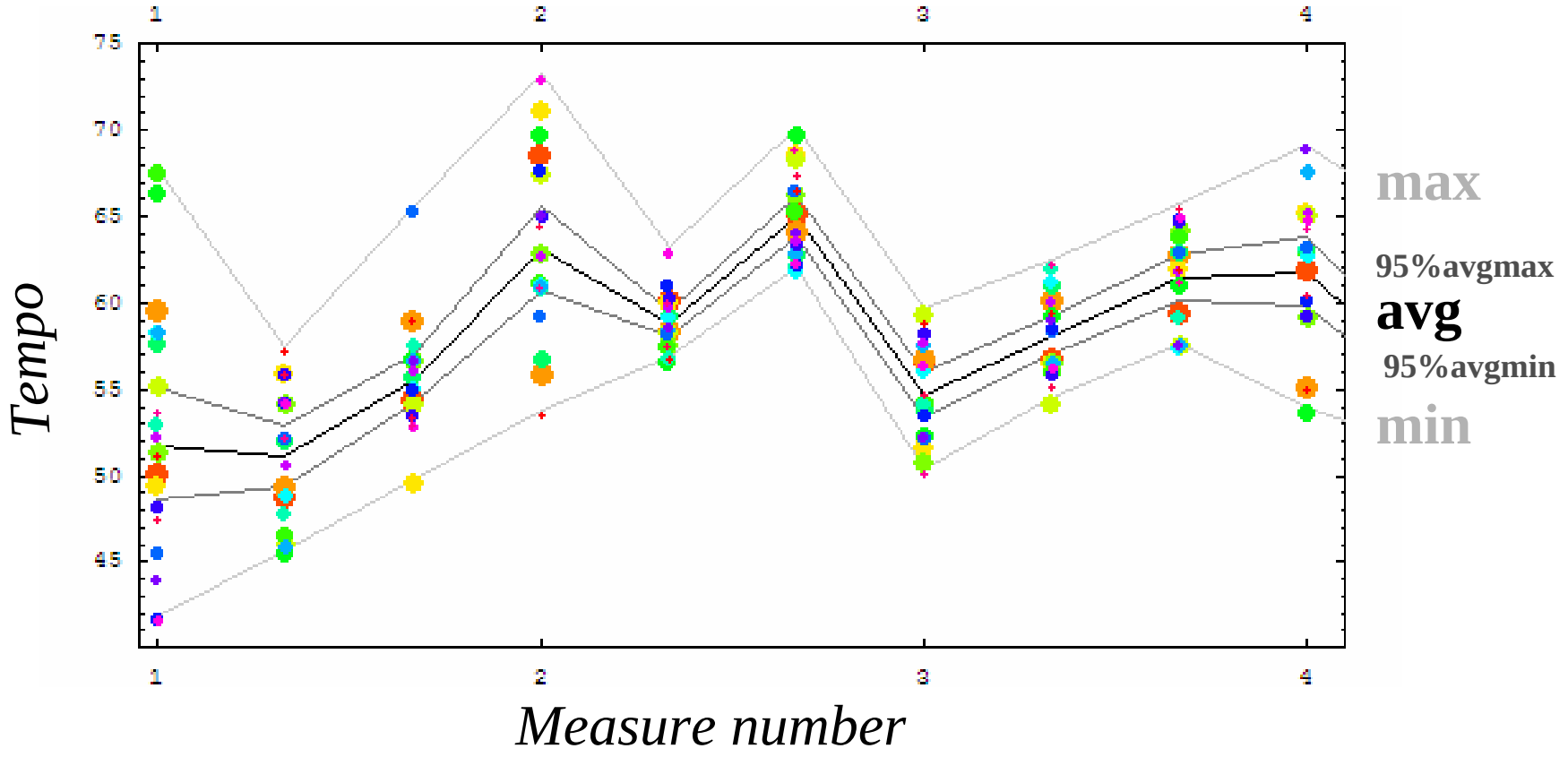


Automatic Score Alignment

Current Work

- **Tempo Plots**
- **Tempo Correlation Analysis**
- **Performance Reconstruction**

Tempo Plots



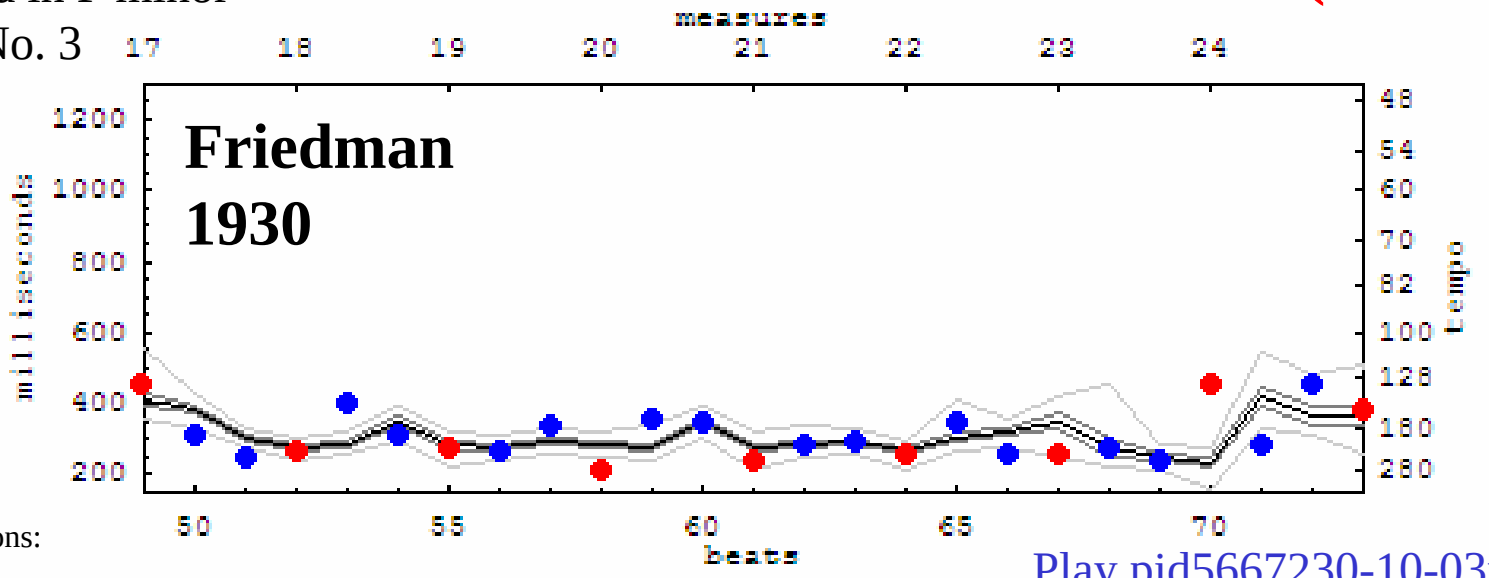
Individual trials
(smaller = earlier trial) &
(red = earlier; purple=later trial)

Friedman 1930
Op. 7, No. 3

Tempo Plots Op. 7, No. 3

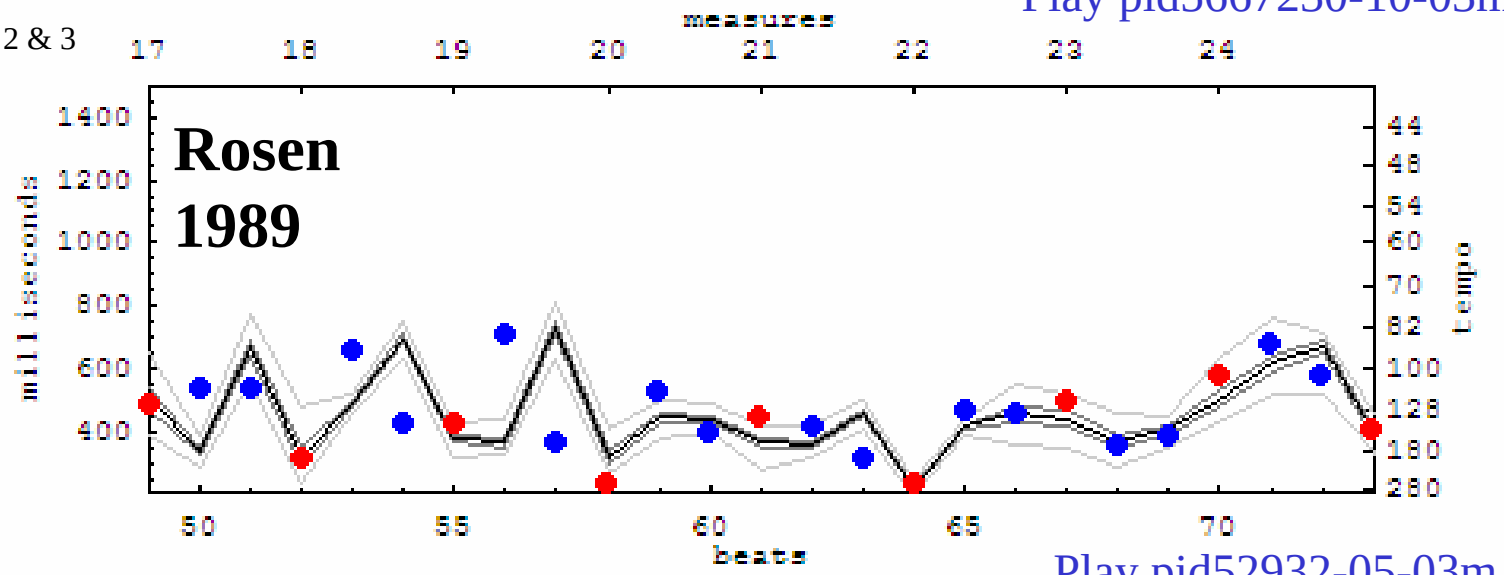
Mazurka in F minor
Op. 7, No. 3

(rubato)



Manual corrections:
Red dot = beat 1
Blue dots = beats 2 & 3

Play pid5667230-10-03m

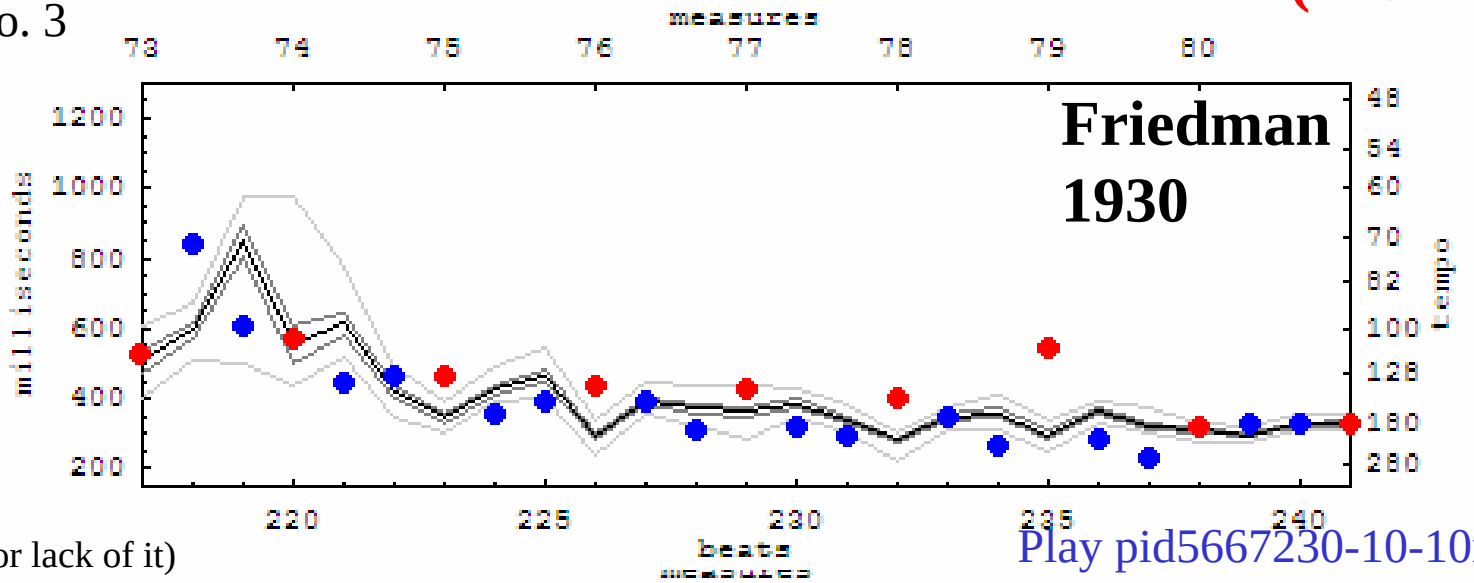


Play pid52932-05-03m

Tempo Plots Op. 7, No. 3 (2)

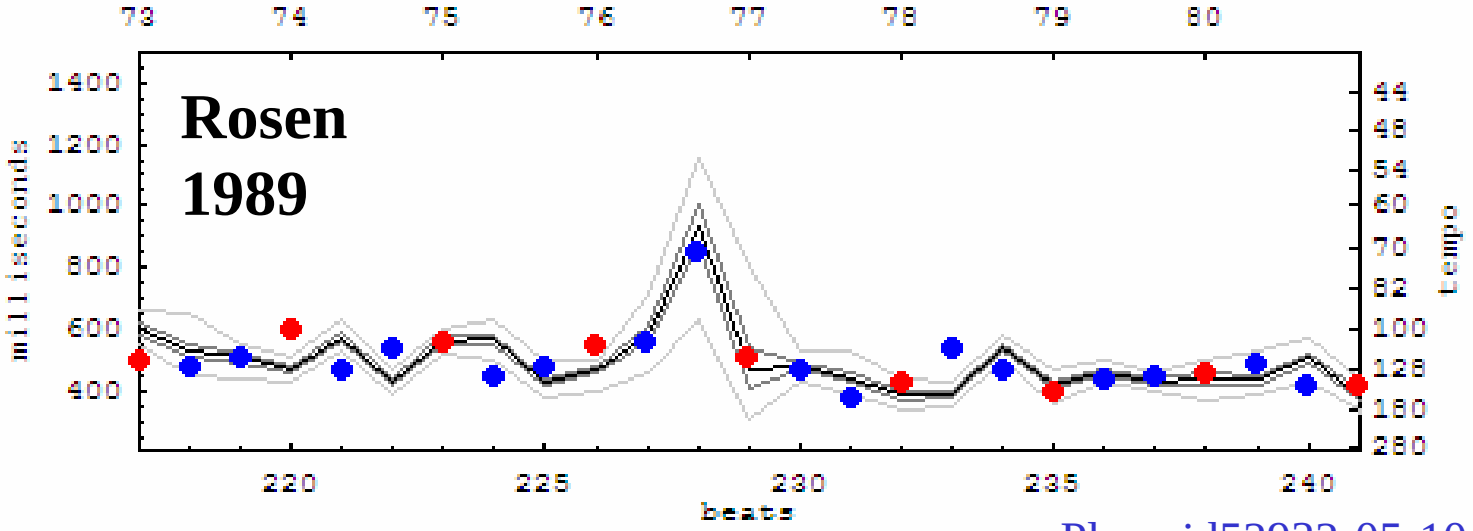
Mazurka in F minor
Op. 7, No. 3

(boundaries)



(Note surprise or lack of it)

Play pid5667230-10-10m



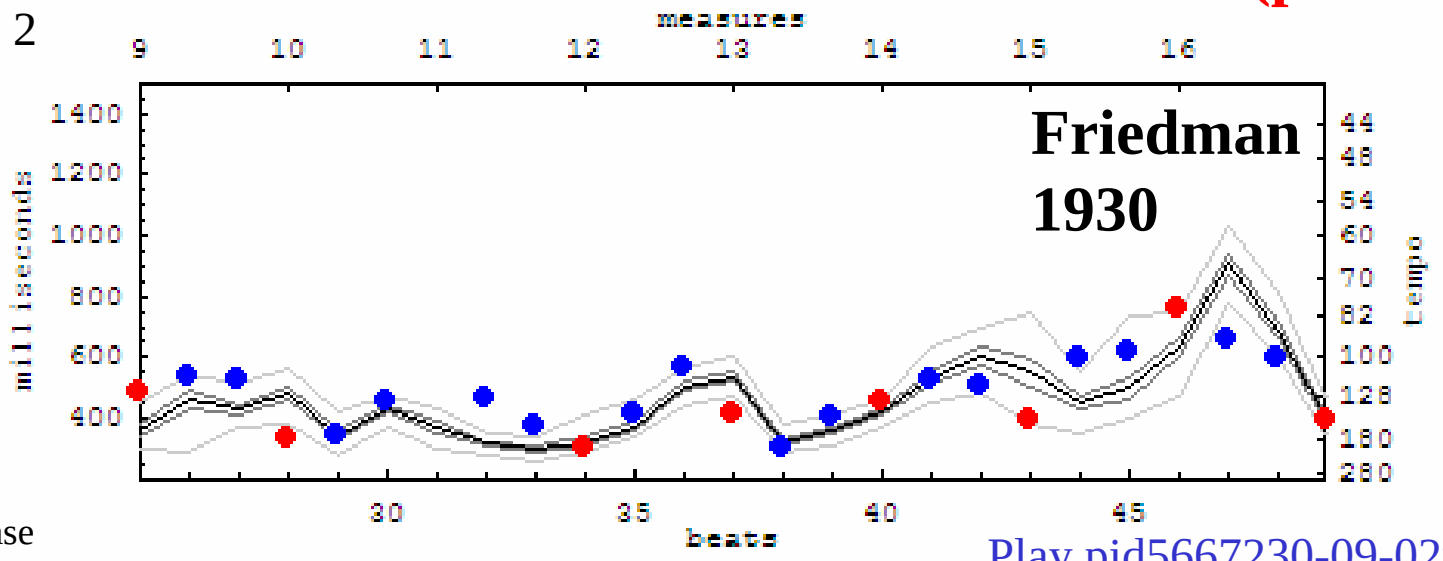
Play pid52932-05-10m

Tempo Plots Op. 7, No. 2

(Third beats red)

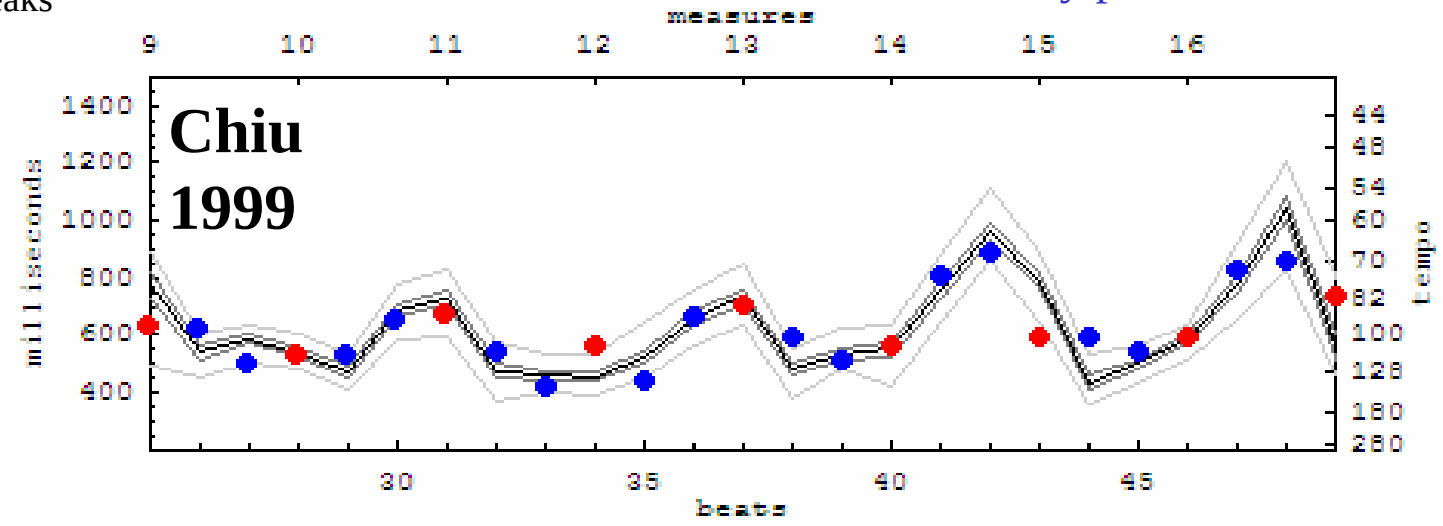
(phrasing)

Mazurka in A minor
Op. 7, No. 2



Very clear phrase boundaries (peaks every two measures):

Play pid5667230-09-02m

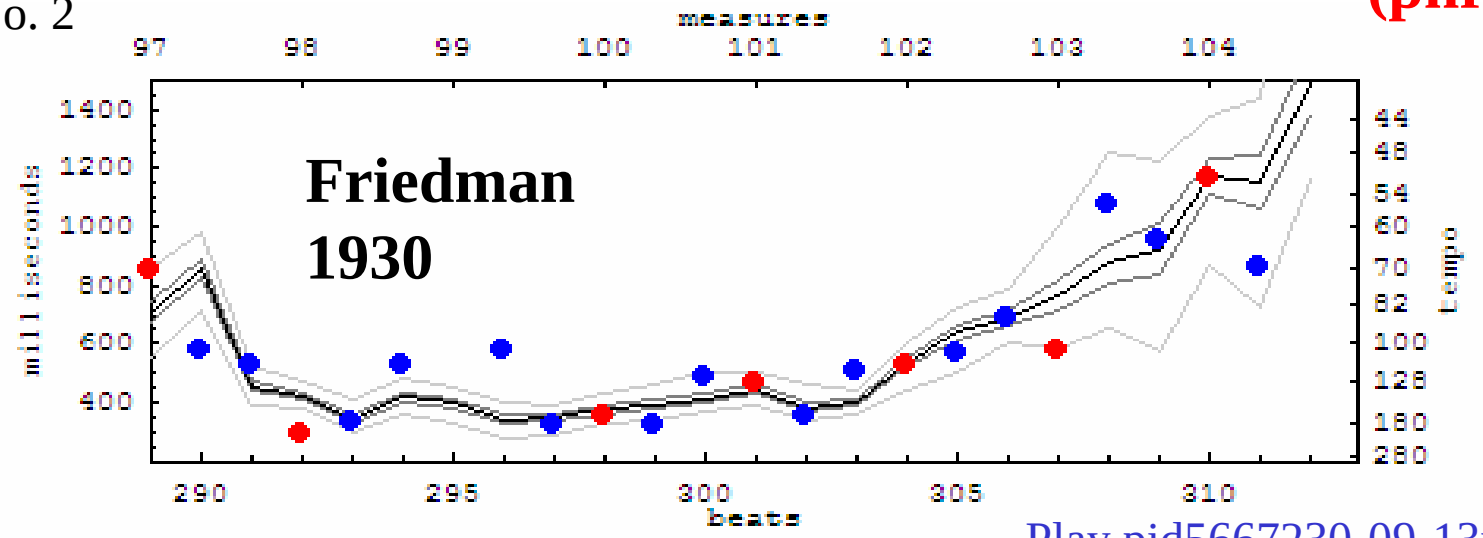


Play pid9048-06-02m

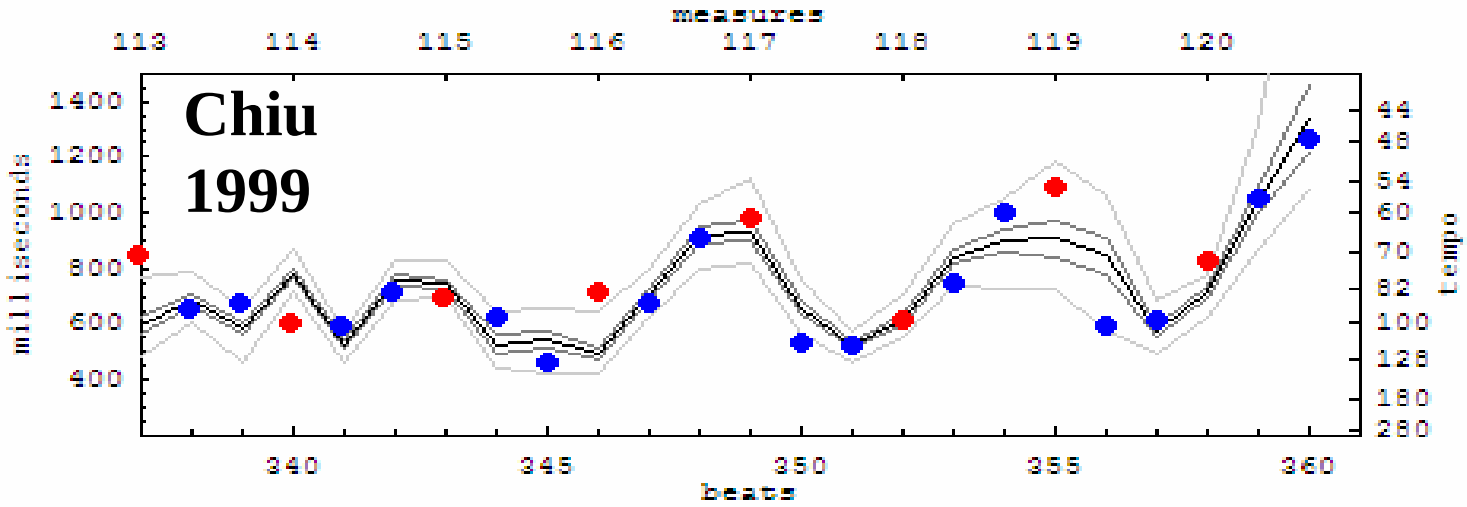
Tempo Plots Op. 7, No. 2 (2)

Mazurka in A minor
Op. 7, No. 2

(Third beats red)
(phrasing)



Play pid5667230-09-13m



Play pid9048-06-15m

Tempo Correlation

Pearson's product moment correlation:

$$\frac{\sum (x - \bar{x})\,(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}$$

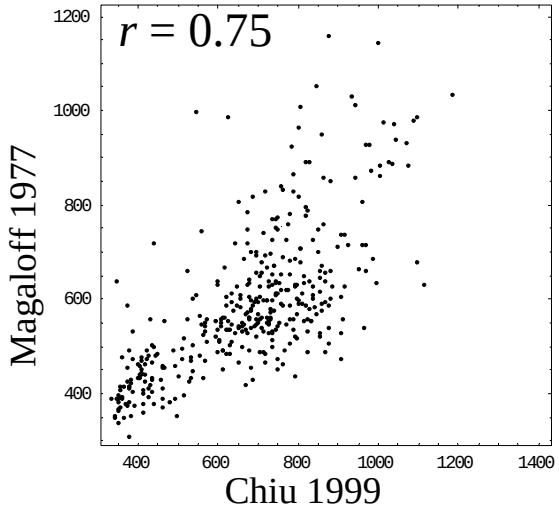
- Correlation value in the range from -1 to +1.
- 1 means exact correlation, 0 means no correlation, -1 is anticorrelation
- Used in the Krumhansl-Schmuckler key-finding algorithm

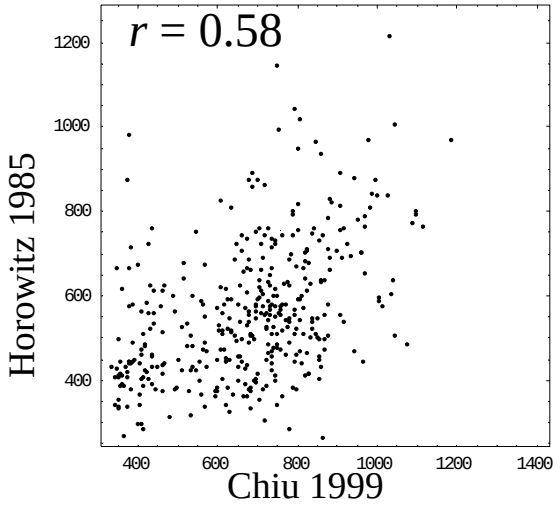
- Other types of correlation metrics, such as:
  Spearman Rank Correlation Coefficient

Tempo Correlation (2)

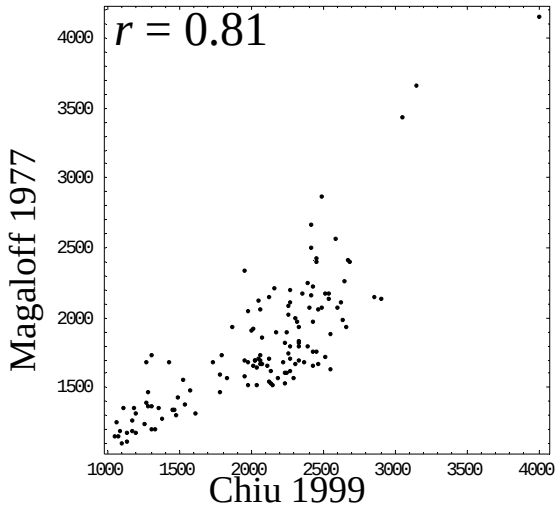
Op. 17, No. 4

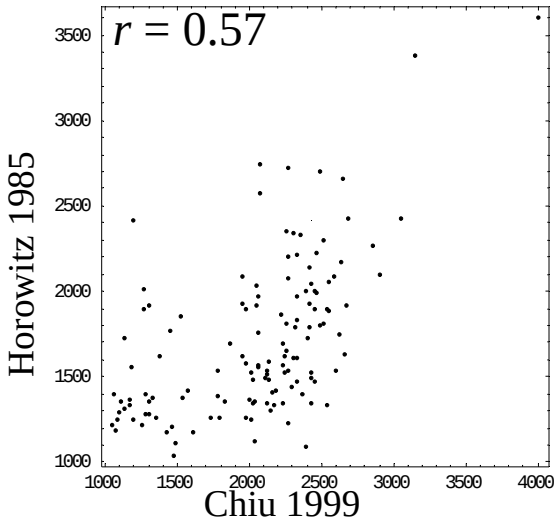
Beat durations:





Measure durations:

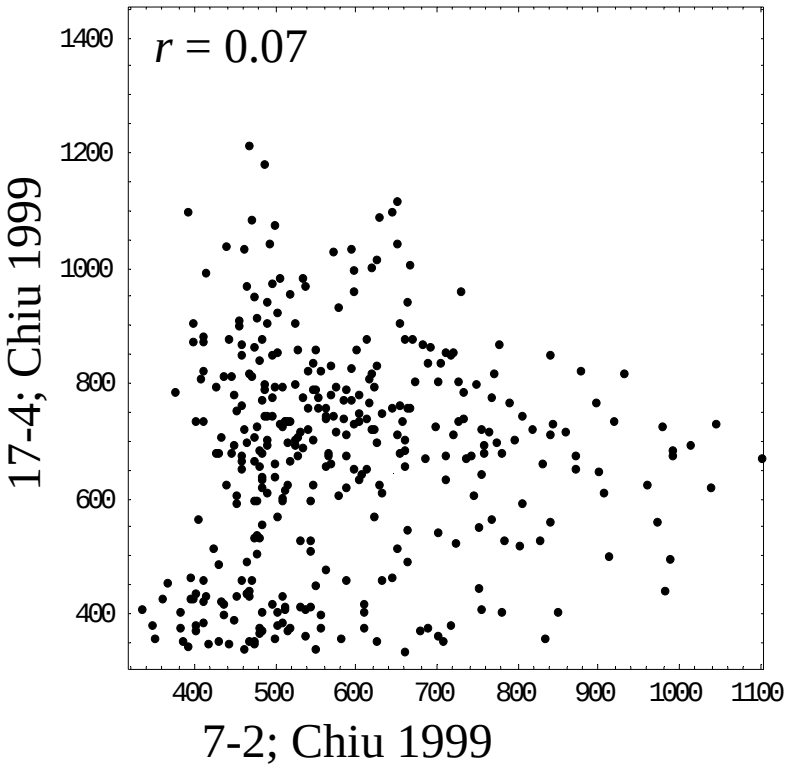




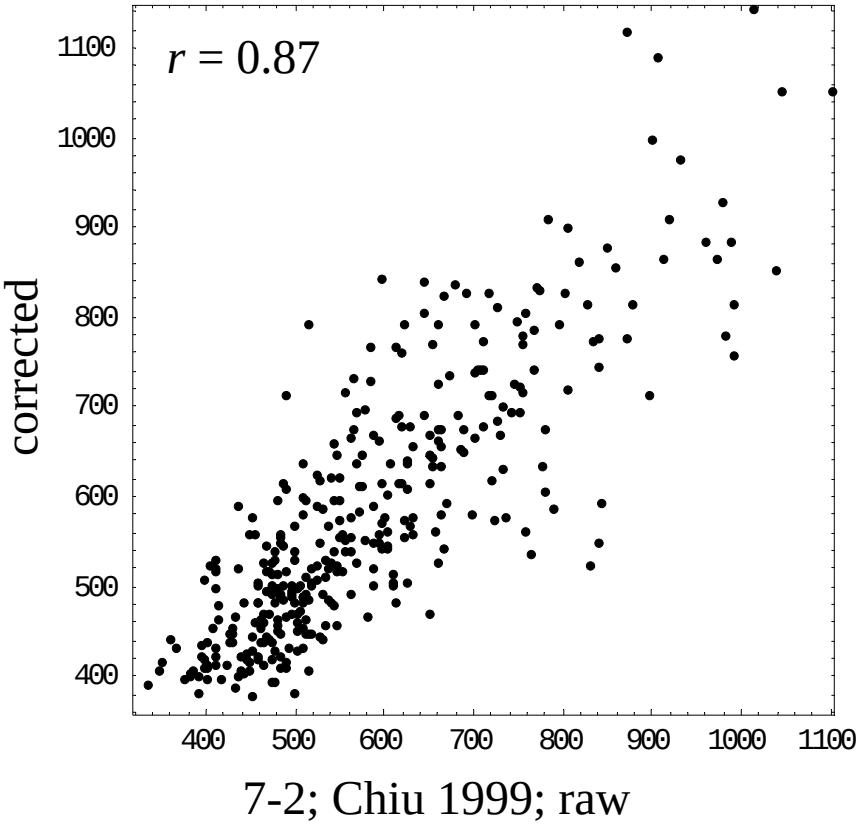
Tempo Correlation (3)

correlation extremes

Comparing two unrelated pieces:

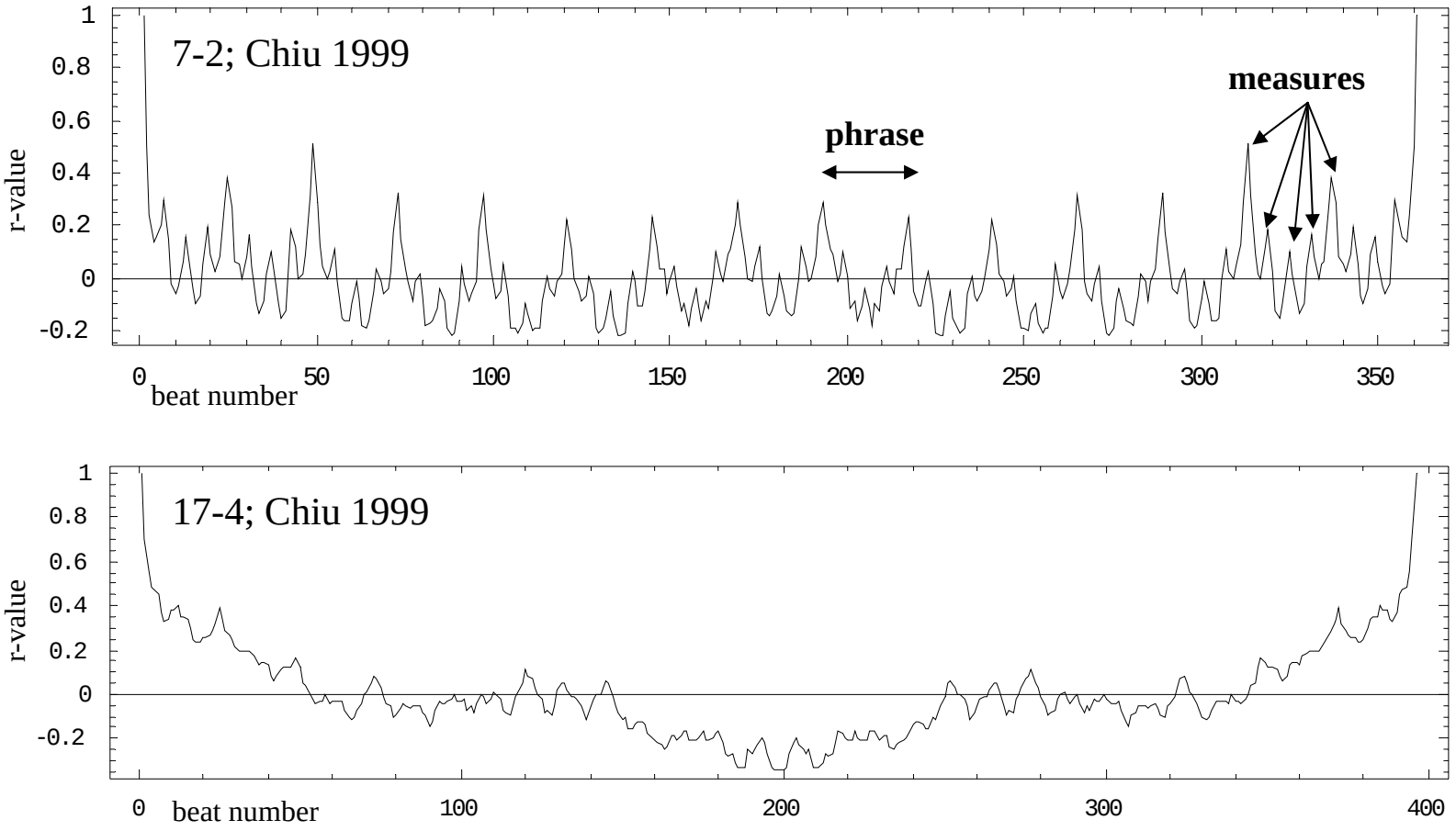


Raw and corrected reverse conduction:



Tempo Correlation (4)

Autocorrelation with shifted performance



Performance Reconstruction

- Simulate performances of the score from various components:

Tempo

- **Constant tempo** → boring
- **Measure tempo**
- **Beat tempo** → phrasing
- **Tempo of offbeats** → jazzing
- **Exact duration of all notes** → Non-simultaneous beat events

Dynamics

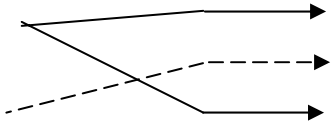
- **Constant Loudness** → boring
- **Chordal Loudness** → dynamics
- **Note Loudness** → voicing

Also durations for: staccato, legato & pedaling

Performance Reconstruction (2)

First Reconstruction:

- Use tap timings to control the tempo of each beat
- Interpolate expected times of offbeats



- Convert score to MIDI using **time data with inferred durations.

- **7-2; Chiu 1999** Play pid9048-06
- **7-2; Chiu 1999 reconstruction** Play pid9048-06-rA
- **simultaneously** Play pid9048-06-sim

Abs times	Score		
**time	**kern		**kern
=1-	=1-		=1-
*	*^		*
2465	([2.C/	8FF\L	2.r
2659	.	8EEn\J	.
2852	.	2CC\	.
3243	.	.	.
=2	=2	=2	=2
3604	4C/]	[2.FF\	2.r
3921	4D-/	.	.
4261	4BBn/	.	.
=3	=3	=3	=3
4569	[2.C/	8FF\L]	2.r
4759	.	8EEn\J	.
4935	.	2CC\	.
5279	.	.	.
=4	=4	=4	=4
5604	4C/]	[2.FF\	2.r
5928	4D-/	.	.
6291	4BBn/)	.	.
=5	=5	=5	=5

Future Work

***Audio*:**

- Minimize alignment errors/Speed alignment process
- Automatic alignment of offbeats after beats are verified
- Non-simultaneous chord note timing offsets
- Note dynamics

Performance Analysis:

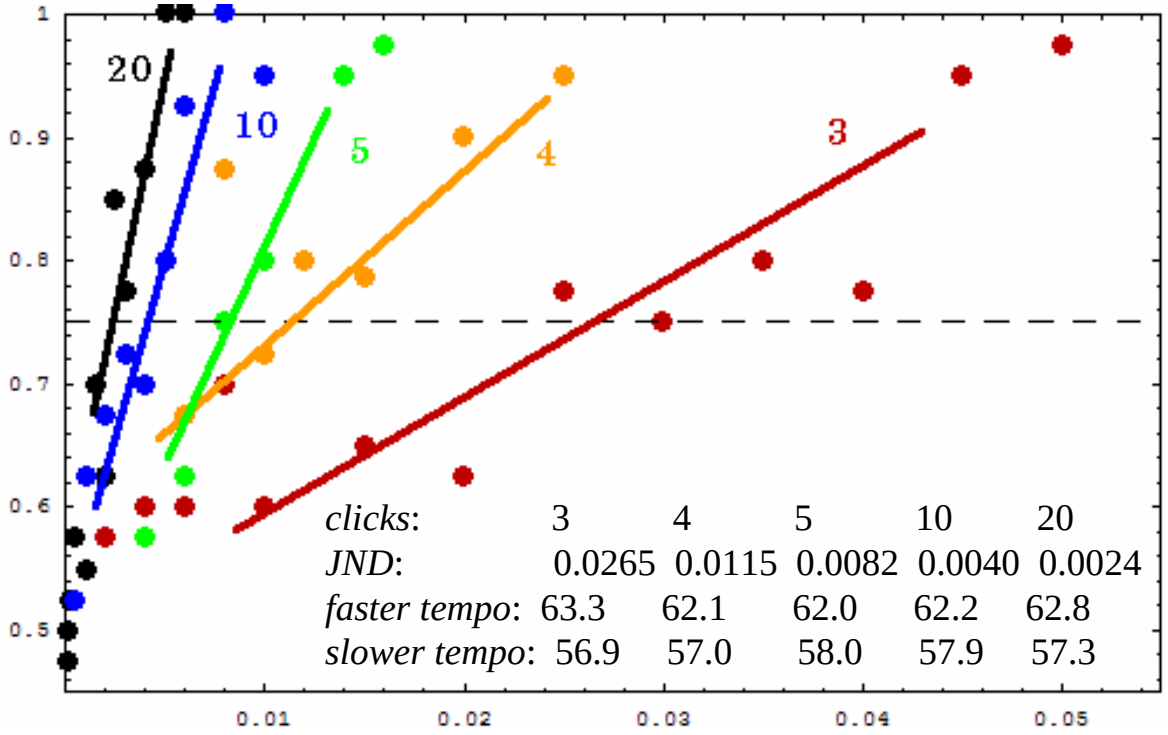
- Characterize and compare performances

  Automatic identification of “schools” of music?

- Identify importance/relation of timing and dynamics

Miscellaneous Slides

Tempo Perception Experiment



10 clicks; 60 MM

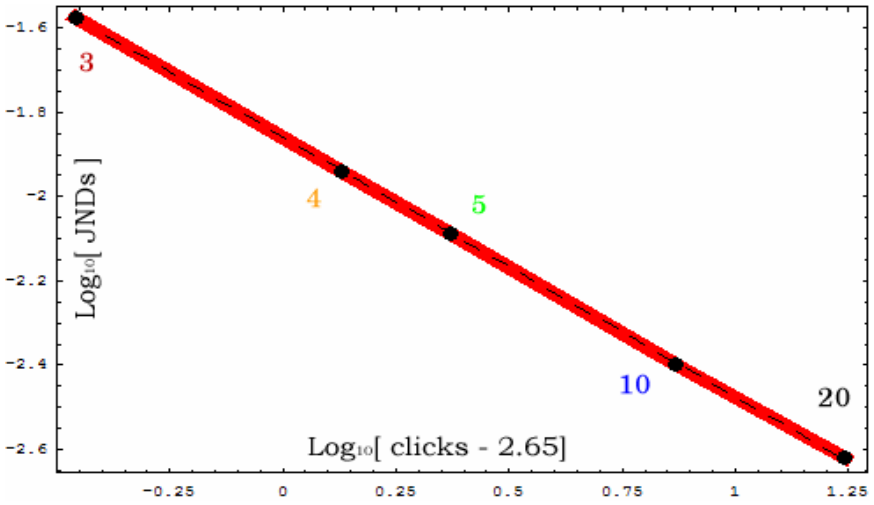
JND * 10

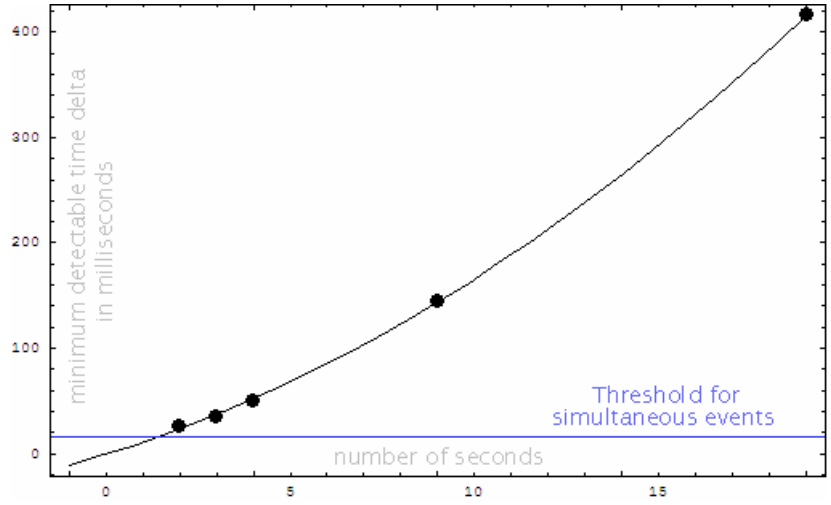
JND * 4

JND

JND/4

JND/10

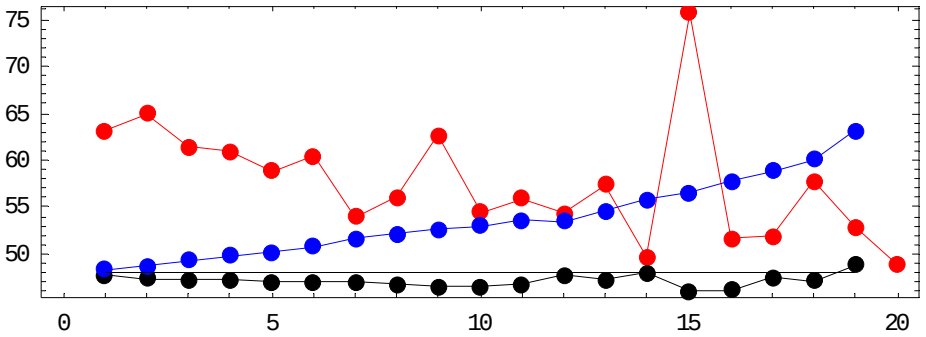


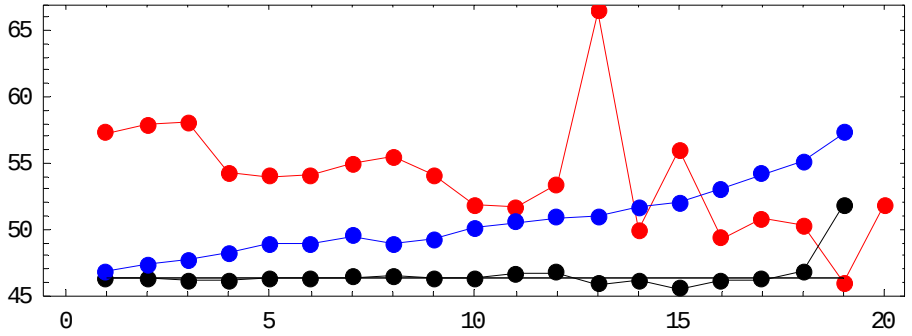


Average Displacement Errors (2)

Mazurka in F Minor, Op. 7, No. 3

Rosen 1989 **Friedman 1930**





slower tempo

Mazurka in A Minor, Op. 7, No. 2

Chiu 1999 **Friedman 1930**