# 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 | Lusada (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 7243585767 26 |

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*

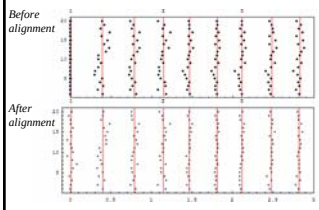
**Example output:**

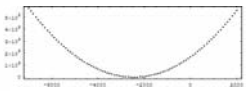
| *Beat duration (quarter note)* | *Metric position* | *Absolute Time (ms)* | *Delta Time (ms)* | |
|---|---|---|---|---|
| ****kern** | ****beat** | ****abstm** | ****deltatime** | |
| =1- | =1- | =1- | =1- | |
| 4 | 1 | 0 | 0 | |
| 4 | 2 | 391 | 391 | |
| 4 | 3 | 741 | 350 | |
| =2 | =2 | =2 | =2 | |
| 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.



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)

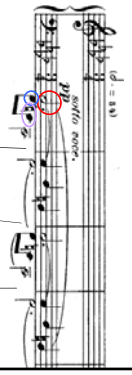
# Tapping Summary Data

| **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

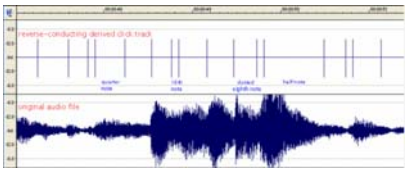
**Created from timed score + tapping summary data**

```
%%%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

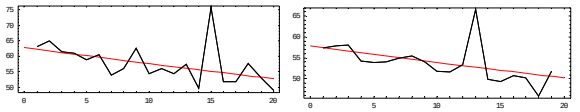


- Align tapped beats within 10 ms by ear/eye in sound editor
- Each beat alignment takes about 1-2 minutes on average
- 300 beats in each mazurka = 1 to 2 days for a performance
- Necessary for evaluation of automatic alignment
- 4 manual corrections done to date (for 7-2 & 7-3)

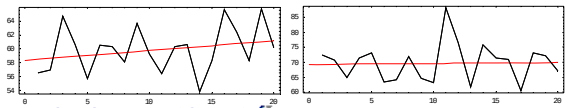
Play pid5667230-10-corr (Friedman 1930)

## Learning Curves for 4 Performances

**Mazurka in F Minor, Op. 7, No. 3**
**Rosen 1989** **Friedman 1930**



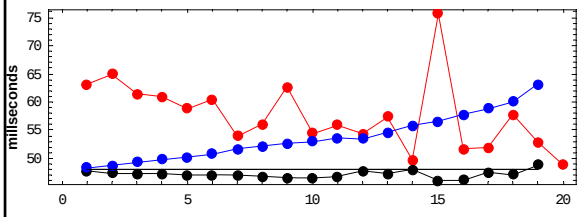
**Mazurka in A Minor, Op. 7, No. 2**
**Chiu 1999** **Friedman 1930**



Play pid9048-06-avg (Chiu 1999)

## Average Displacement Errors

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



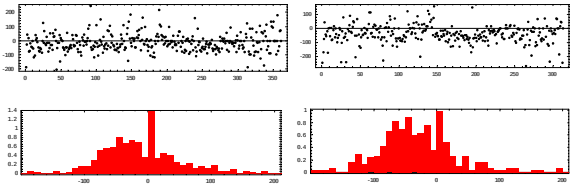

**= individual trial average displacement errors**
**= dropping more and more later trials**
**= dropping more and more earlier trials**

## 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.**

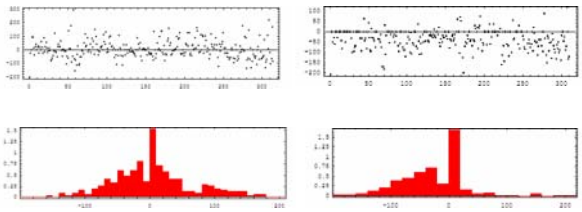
**Mazurka in A Minor, Op. 7, No. 2**
**Chiu 1999** **Friedman 1930**



**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**

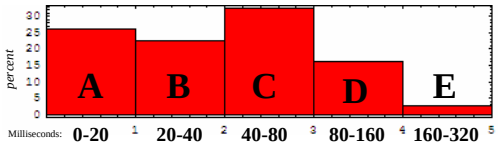


**48 ms avg correction; +5 ms overall shift** **48 ms avg correction; -27 ms overall shift**

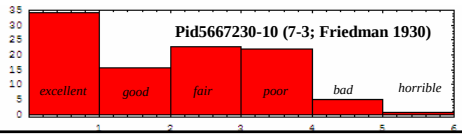
## Beat Accuracy Metric

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

**pid9048-06 (7-2; Chiu 1999)**




• Human tapper: 48% of beats within 40 milliseconds

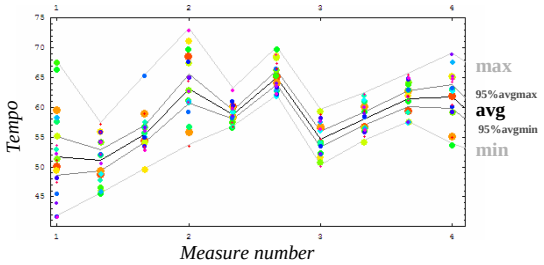



## Automatic Score Alignment

## Current Work

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

## Tempo Plots



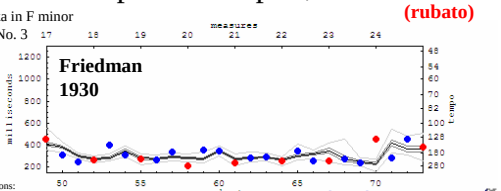

**Individual trials**
**(smaller = earlier trial) &**
**(red = earlier; purple=later trial)**

Friedman 1930
Op. 7, No. 3

## Tempo Plots Op. 7, No. 3

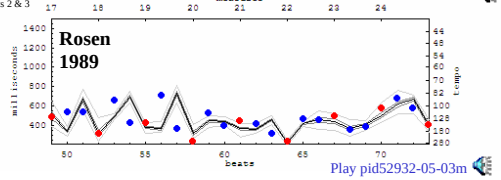
Mazurka in F minor
Op. 7, No. 3

**(rubato)**




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

Play pid5667230-10-03m

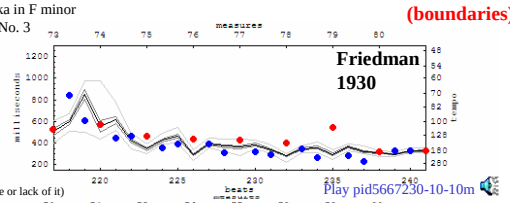



Play pid52932-05-03m

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

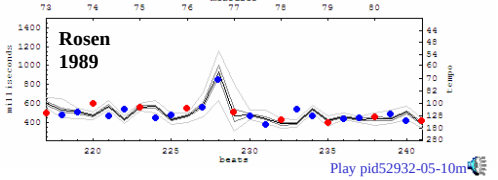
Mazurka in F minor
Op. 7, No. 3

**(boundaries)**




(Note surprise or lack of it)

Play pid5667230-10-10m



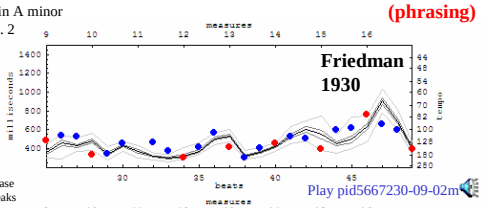

Play pid52932-05-10m

## Tempo Plots Op. 7, No. 2

(Third beats red)

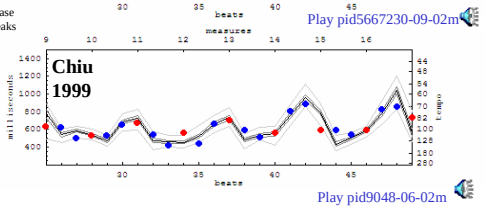
Mazurka in A minor
Op. 7, No. 2

**(phrasing)**




Very clear phrase boundaries (peaks every two measures):

Play pid5667230-09-02m



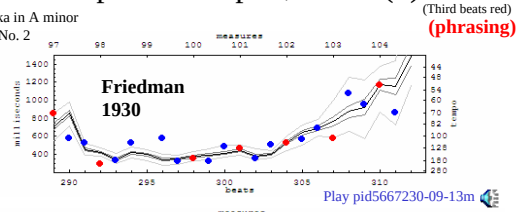

Play pid9048-06-02m

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

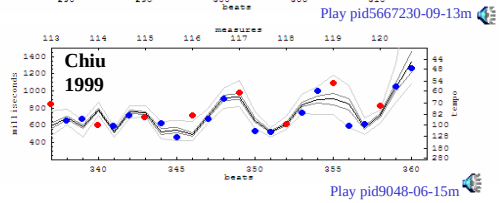
(Third beats red)

Mazurka in A minor
Op. 7, No. 2

**(phrasing)**




Play pid5667230-09-13m




Play pid9048-06-15m

# Tempo Correlation

Pearson's product moment correlation:

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

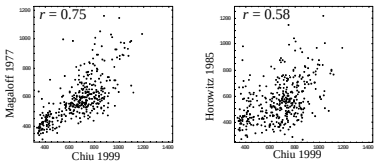
- Correlation value in the range from -1 to +1.
- 1 means exact correlation, 0 means no correlation, -1 is anticorrelation
- Used in the Krumhansl-Schmuckler key-finding algorithm

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

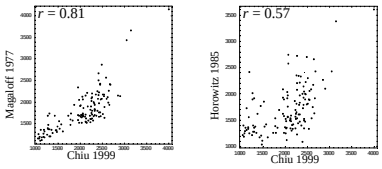
# Tempo Correlation (2)

Op. 17, No. 4

Beat durations:



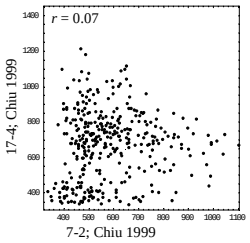

Measure durations:



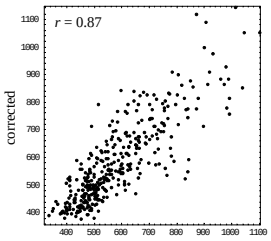

# Tempo Correlation (3)

**correlation extremes**

Comparing two unrelated pieces:

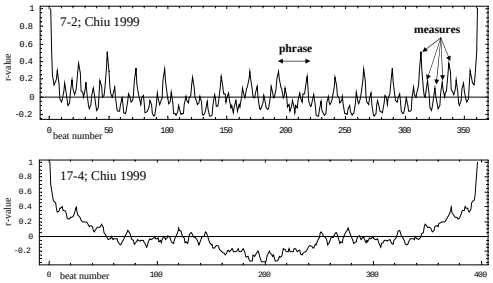



Raw and corrected reverse conduction:




# 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 |

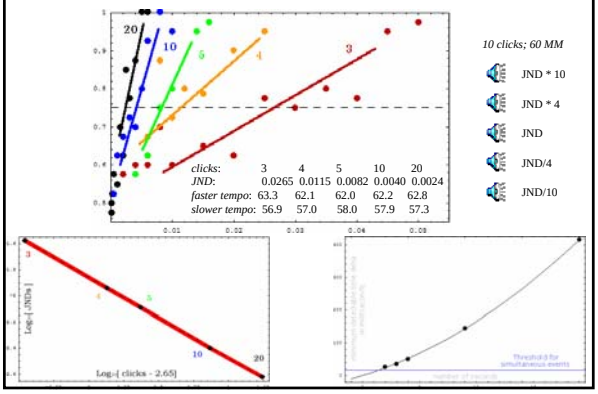
## Future Work

***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

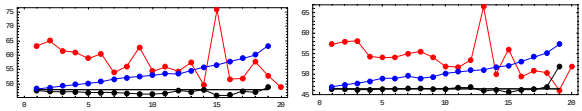
## Miscellaneous Slides

## Tempo Perception Experiment




## 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**