# 人工知能研究室

指導教員　　水谷哲也　講師
学生数　　現在1人 (B4)
募集人数　　3人
研究内容

人工知能とプログラム理論の融合による知見を用いた音楽情報学の研究
- 自動演奏システムの仕様の論理的表現・実装・正当性検証
- 音楽の構造的機能とそれに基づく演奏創造
  楽曲の構造的分析と演奏表情との関係，演奏ルールの論理的表現，
  演奏表情の視覚化，運指情報の論理的表現・決定システムの構築

単にコンピュータで音楽を演奏するのではありません．
音楽における人間の「知性」と「感性」，「知」と「思」を論理的・数理的に捉えて
モデル化する研究を行います．

なお，特に希望がある場合は，プログラム理論に関する研究，特に
　実時間知的プログラムの検証，検証理論の構築
　具体例(自動演奏システムなど)への適用・解析
などを行うこともできます．
教員と相談の上，その他の興味を持ったテーマを選ぶことは差し支えありません．

# 演奏表情の自動生成
# 演奏モデルの作成

どのようにして人間らしい表情豊かな演奏を生成するか
人間らしい演奏のモデルをどのように作成

楽曲構造分析

楽曲に内在する緊張，誘引などの抽出

演奏の解析
(重回帰分析など統計的手法を用いる)

# GTTM and TPS

GTTM (Generative Tonal Theory of Music)[Jackendoff83]:

Cognitive Theory of Tonal Music

Analyzing music by structural rules of music and hierarchical musical structures

Introducing prolongational reduction structure and prolongational tree

TPS (Tonal Pitch Space) [Lerdahl01]

Succession of GTTM

Introducing structures of pitch, tone, chord, etc.

Introducing harmonic tension and melodic attraction values.

[Jackendoff83] F. Lerdahl and R. Jackendoff, A Generative Theory of Tonal Music, The MIT Press, Cambridge, 1983.

[Lerdahl01] F. Lerdahl, Tonal Pitch Space, Oxford University Press, Oxford, 2001.

# GTTM and TPS

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Introducing prolongational reduction structure and prolongational tree

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Succession of GTT

Introducing stru

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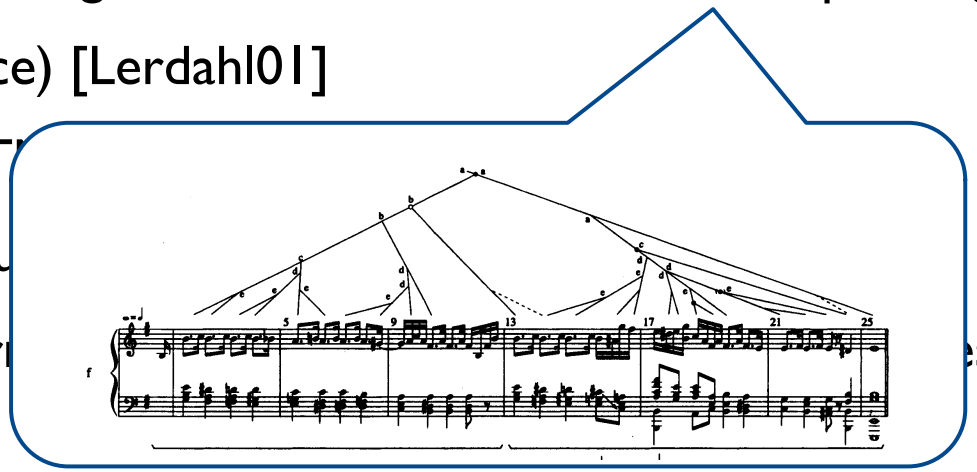
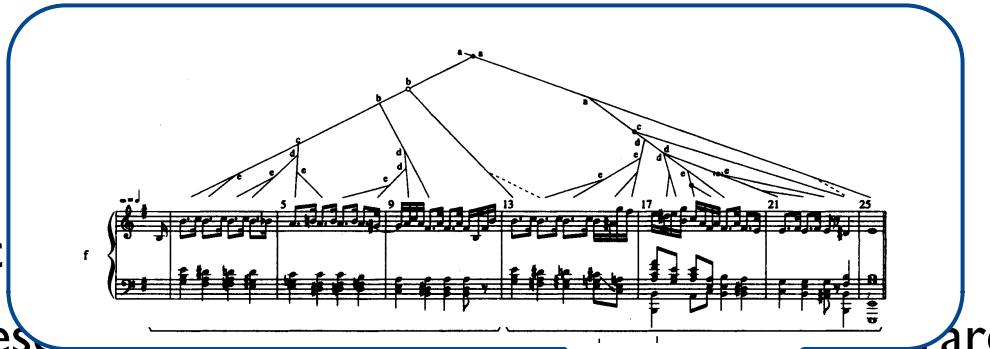


es.

[Jackendoff83] F. Lerdahl and R. Jackendoff, A Generative Theory of Tonal Music, The MIT Press, Cambridge, 1983.

[Lerdahl01] F. Lerdahl, Tonal Pitch Space, Oxford University Press, Oxford, 2001.

# Harmonic Tension Value



Hierarc

Represe archica

Assigned to each chord

Defined by the *prolongational tree* and the *chord distance*

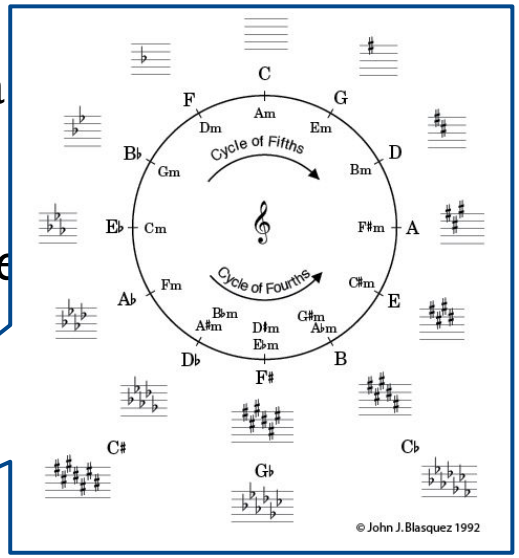
The p*rolongational tree* :

the hierarchical relationship

between each harmonic and melodi ent

The *chord distance*:

defined in the cycle of fifth of diatonic scale



# Melodic Attraction Values

Realized Voice-Leading Attraction Value :

Representing how attracts a chord in a stream

Assigned to each chord

Defined by the *anchoring strength*

and number of semitone intervals of two pitches

The *anchoring strength*:

representing of individual attracting power of each pitch

in the key

# Sample Data

Actual musical performance data

obtained from CrestMusePEDB [Crest2012]

Distinguished Pianists:

C. Arrau, V. D. Ashkenazy, W. Backhaus, C. Eschenbach,

G. H. Gould, I. Haebler, L. Kraus, A. deLarrocha,

H.Nakamura, M. J. Pires, N. Shimizu

Unnamed Pianists:

amateur or semiprofessional;

ungraduate in or graduates of music universities

[Crest2012] http://www.crestmuse.jp/pedb/

| Musical Data used in the Analysis | | |
|---|---|---|
| Music Title (Composer) | Data | |
| | Distinguished Pianists | Unnamed Pianists |
| Piano Sonata No. 11 in A major, K. 331 (W. A. Mozart) | 8 | 33 |
| Piano Sonata No. 8 in C minor, Op. 13, “Sonata Pathétique” (L. v. Beethoven) | 3 | 32 |
| Kinderscenen, Op. 15, No. 7, in F major, “Träumerei” (R. A. Schumann) | 2 | 1 |
| Étude Op. 10, No. 3, in E major (F. F. Chopin) | 1 | 1 |

# Dependent and Independent Variables

Dependent Variable (in the multiple regression analysis):

local tempo or local volume of the corresponding event

Independent variables

| | | |
|---|---|---|
| Hierarchical global tension value | } | nonnegative integer |
| Realized voice-leading attraction value | | |
| expression marks (accent, crescendo, etc.) | | 1 if exists and 0 otherwise |

# Experiment

- Partial regression coef
  regression analyses are
  - the existence of ea
- Averages of each coeff
  for each piece, are calc
  - Average of coefficie
- Comparing and Evaluating them
  - Significant differences of performances between distinguished and unnamed pianists are obtained.

**MUSICAL DATA USED IN THE ANALYSIS**

| Music Title (Composer) | Data | |
|---|---|---|
| | Distinguished Pianists | Unnamed Pianists |
| Piano Sonata No. 11 in A major, K. 331 (W. A. Mozart) | 8 | 33 |
| Piano Sonata No. 8 in C minor, Op. 13, “Sonata Pathétique” (L. v. Beethoven) | 3 | 32 |
| Kinderscenen, Op. 15, No. 7, in F major, “Träumerei” (R. A. Schumann) | 2 | 1 |
| Étude Op. 10, No. 3, in E major (F. F. Chopin) | 1 | 1 |

# Result

**The Regression Coefficient of the Independent Variables for Tempo**

| Independent Variables | Average of Regression Coefficient | |
|---|---|---|
| | Distinguished Pianists | Unnamed Pianists |
| piano_start_M | -0.162 | -0.158 |
| slur_start_M | NA | 0.0351 |
| slur_cont_M | 0.0485 | 0.0505 |
| slur_end_M | -0.0331 | -0.103 |
| cre_start_A | 0.194 | NA |
| cre_end_M | -0.146 | NA |
| decre_cont_M | 0.0968 | NA |
| graced_M | -0.269 | NA |
| slur_start_A | -0.0292 | -0.0557 |
| slur_end_A | 0.0801 | -0.0594 |
| rit_start | NA | -0.337 |
| rit_cont | -0.247 | NA |
| rit_end | -0.440 | NA |
| tension | 0.00319 | -0.0025 |

**The Regression Coefficient of the Independent Variables for Volume**

| Independent Variables | Average of Regression Coefficient | |
|---|---|---|
| | Distinguished Pianists | Unnamed Pianists |
| forte_start_M | 0.298 | NA |
| piano_start_M | NA | -0.112 |
| slur_start_M | NA | -0.103 |
| slur_cont_M | NA | -0.0533 |
| slur_end_M | NA | -0.03502 |
| decre_cont_M | -0.211 | NA |
| pre_grace_M | -0.0612 | NA |
| slur_start_A | NA | 0.0691 |
| slur_end_A | -0.0894 | NA |
| cre_start_A | 0.254 | NA |
| cre_cont_A | 0.142 | NA |
| pedal_on | 0.00880 | NA |
| tension | 0.00319 | 0.00671 |
| attraction | 0.0130 | 0.242 |

# Result

**The Regression Coefficient of the Independent Variables for Tempo**

| Independent Variables | Average of Regression Coefficient | |
|---|---|---|
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| rit_start | NA | -0.337 |
| rit_cont | -0.247 | NA |
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Expression marks for volume; affects Tempo

**The Regression Coefficient of the Independent Variables for Volume**

| Independent Variables | Average of Regression Coefficient | |
|---|---|---|
| | Distinguished Pianists | Unnamed Pianists |
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| piano_start_M | NA | -0.112 |
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| slur_end_M | NA | -0.03502 |
| decre_cont_M | -0.211 | NA |
| pre_grace_M | -0.0612 | NA |
| slur_start_A | NA | 0.0691 |
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| cre_start_A | 0.254 | NA |
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# Result

| The Regression Coefficient of the Independent Variables for Tempo | | |
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| | Distinguished Pianists | Unnamed Pianists |
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| slur_start_M | NA | 0.0351 |
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| graced_M | -0.269 | NA |
| slur_start_A | -0.0292 | -0.0557 |
| slur_end_A | 0.0801 | -0.0594 |
| rit_start | NA | -0.337 |
| rit_cont | -0.247 | NA |
| rit_end | -0.440 | NA |
| tension | 0.00319 | -0.0025 |

| The Regression Coefficient of the Independent Variables for Volume | | |
|---|---|---|
| Independen Variables | cient | |
| | | |
| forte_start_M | 0.298 | NA |
| piano_start_M | NA | -0.112 |
| slur_start_M | NA | -0.103 |
| slur_cont_M | NA | -0.0533 |
| slur_end_M | NA | -0.03502 |
| decre_cont_M | -0.211 | NA |
| pre_grace_M | -0.0612 | NA |
| slur_start_A | NA | 0.0691 |
| slur_end_A | -0.0894 | NA |
| cre_start_A | 0.254 | NA |
| cre_cont_A | 0.142 | NA |
| pedal_on | 0.00880 | NA |
| tension | 0.00319 | 0.00671 |
| attraction | 0.0130 | 0.242 |

Exclusive

# Result

| The Regression Coefficient of the Independent Variables for Tempo | | |
|---|---|---|
| Independent Variables | Average of Regre | |
| | Distinguished Pianists | |
| piano_start_M | -0.162 | |
| slur_start_M | NA | 0.0351 |
| slur_cont_M | 0.0485 | 0.0505 |
| slur_end_M | -0.0331 | -0.103 |
| cre_start_A | 0.194 | NA |
| cre_end_M | -0.146 | NA |
| decre_cont_M | 0.0968 | NA |
| graced_M | -0.269 | NA |
| slur_start_A | -0.0292 | -0.0557 |
| slur_end_A | 0.0801 | -0.0594 |
| rit_start | NA | -0.337 |
| rit_cont | -0.247 | NA |
| rit_end | -0.440 | NA |
| tension | 0.00319 | -0.0025 |

| The Regression Coefficient of the Independent Variables for Volume | | |
|---|---|---|
| | | Coefficient |
| | | med<br>sts |
| forte_start_M | | NA |
| piano_start_M | NA | -0.112 |
| slur_start_M | NA | -0.103 |
| slur_cont_M | NA | -0.0533 |
| slur_end_M | NA | -0.03502 |
| decre_cont_M | -0.211 | NA |
| pre_grace_M | -0.0612 | NA |
| slur_start_A | NA | 0.0691 |
| slur_end_A | -0.0894 | NA |
| cre_start_A | 0.254 | NA |
| cre_cont_A | 0.142 | NA |
| pedal_on | 0.00880 | NA |
| tension | 0.00319 | 0.00671 |
| attraction | 0.0130 | 0.242 |

*Distinguished pianists* do not use *piano* for volume

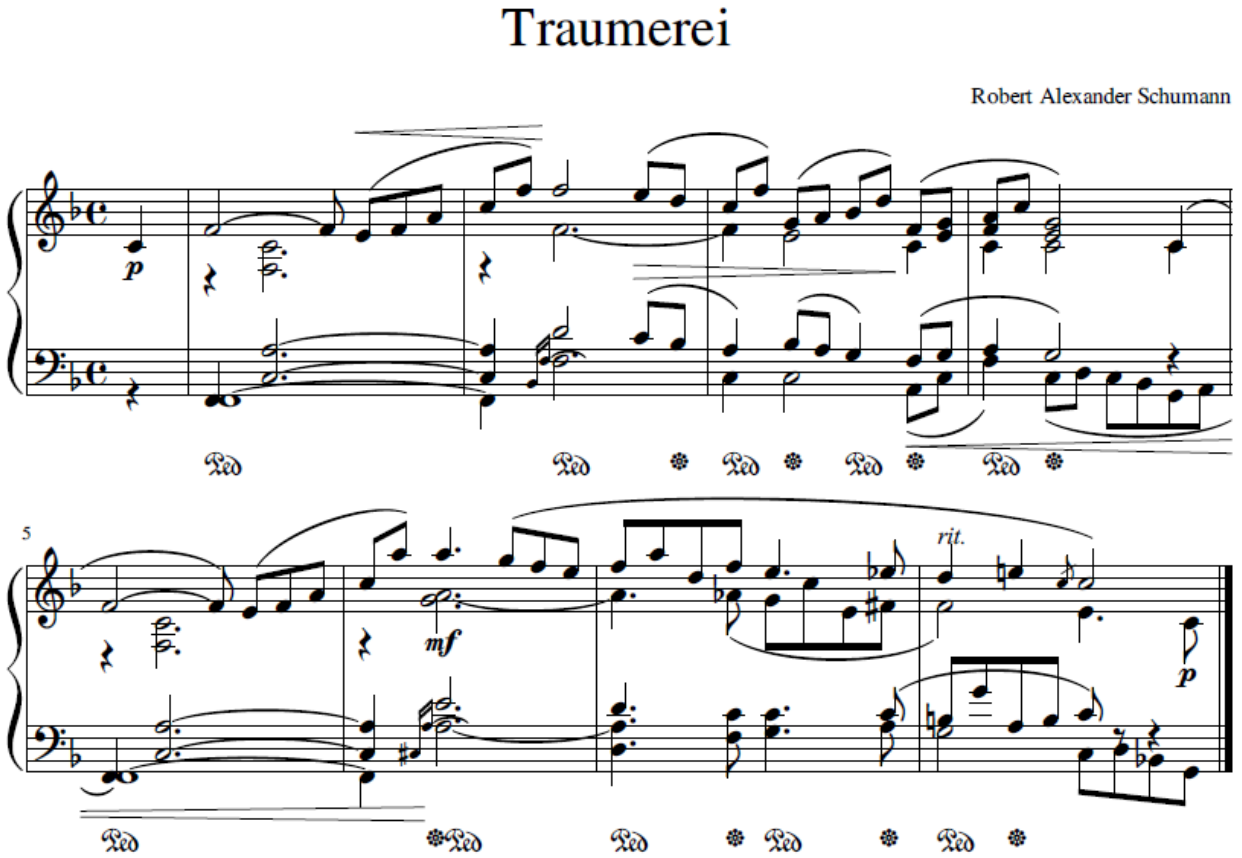
# Result

| The Regression Coefficient of the Independent Variables for Tempo | | |
|---|---|---|
| Independent Variables | Average of Regression Coefficient | |
| | Distinguished Pianists | Unnamed Pianists |
| piano_start_M | -0.162 | -0.158 |
| slur_start_M | NA | 0.0351 |
| slur_cont_M | 0.0485 | 0.0505 |
| slur_end_M | -0.0331 | -0.103 |
| cre_start_A | 0.194 | NA |
| cre_end_M | -0.146 | NA |
| decre_cont_M | 0.0968 | NA |
| graced_M | -0.269 | NA |
| s | | |
| s | | |
| ri | | |
| ri | | |
| rit_end | -0.440 | NA |
| tension | 0.00319 | -0.0025 |

| The Regression Coefficient of the Independent Variables for Volume | | |
|---|---|---|
| Independent Variables | Average of Regression Coefficient | |
| | Distinguished Pianists | Unnamed Pianists |
| forte_start_M | 0.298 | NA |
| piano_start_M | NA | -0.112 |
| slur_start_M | NA | -0.103 |
| slur_cont_M | NA | -0.0533 |
| slur_end_M | NA | -0.03502 |
| decre_cont_M | -0.211 | NA |
| pre_grace_M | -0.0612 | NA |
| | | 0691 |
| | | |
| | | |
| | | |
| | | NA |
| tension | 0.00319 | 0.00671 |
| attraction | 0.0130 | 0.242 |

Tension affects both tempo and volume
Attraction affects volume

# Demonstration:
# Analysis of Performance of Traumerei by Ashkenazy



# Sequential Tonal Tension Rules

Also representing of the tension in music score hierarchically

Assigned to each chord

Defined by

the ***features of itself***,

i.e.

whether its melodic note is ***third*** or ***fifth*** or otherwise,

whether it is ***inversion*** or not, etc.

and also

***the chord distance*** between ***it*** and ***the chord just preceding it***.

# Analyses

Music Data

| Composer | Music Title | Pianist |
|---|---|---|
| L. v. Beethoven | Piano Sonata No. 8 in C minor, Op. 13, "Sonata Pathétique" | C.Arrau |
| | | V. D. Ashkenazy |
| | | W. Backhaus |
| F.F. Chopin | Nocturne in E-flat major, Op. 9, No. 2 | V.D. Ashkenazy |
| | | S. S. Bunin |
| | | V. S. Horowitz |
| | | M. J. Pires |
| M.A. Mozart | Piano Sonata No. 11 in A major, K. 331, Movement 1 | C. Eschenbach |
| | | G. H. Gould |
| | | I. Haebler |
| | | L. Kraus |
| | | A. deLarrocha |
| | | H. Nakamura |
| | | M. J. Pires |
| | | N. Shimizu |
| | Piano Sonata No. 16 in C major, K. 545, Movement 1 | M. J. Pires |

# Results of the regression analyses

1. The tension values vary widely depending on music pieces and pianists.
2. The values of the coefficient of determination of the hierarchical tension values are better than those of the sequential ones.
   Thus, the former can describe music expression more precisely than the latter.

| Result of the analysis of Sonata Pathétique | | | | | |
|---|---|---|---|---|---|
| Pianist | Indep | Tension | Coeff | AIC | p |
| Arrau | tempo | hie. | 0.157 | Y | ** |
| | | seq. | 0.176 | Y | ** |
| | volume | hie. | 0.284 | Y | ** |
| | | seq. | 0.319 | Y | ** |
| Ashkenazy | tempo | hie. | 0.158 | N | - |
| | | seq. | 0.158 | N | - |
| | volume | hie. | 0.257 | Y | ** |
| | | seq. | 0.0933 | N | - |
| Backhaus | tempo | hie. | 0.207 | N | - |
| | | seq. | 0.248 | Y | |
| | volume | hie. | 0.329 | Y | ** |
| | | seq. | 0.221 | N | - |

3. In some performances, e.g. Nocturne performed by Horowitz, the sequential tension rules can be described these expression trends more precisely than the hierarchical ones.

| Result of the analysis of Nocturne | | | | | |
|---|---|---|---|---|---|
| Pianist | Indep | Tension | Coeff | AIC | p |
| Ashkenazy | tempo | hie. | 0.245 | N | - |
| | | seq. | 0.245 | N | - |
| | volume | hie. | 0.471 | Y | ** |
| | | seq. | 0.369 | Y | * |
| Bunin | tempo | hie. | 0.252 | N | - |
| | | seq. | 0.252 | N | - |
| | volume | hie. | 0.346 | Y | |
| | | seq. | 0.330 | N | - |
| Horowitz | tempo | hie. | 0.172 | N | - |
| | | seq. | 0.172 | N | - |
| | volume | hie. | 0.441 | N | - |
| | | seq. | 0.457 | Y | ** |
| Pires | tempo | hie. | 0.281 | N | - |
| | | seq. | 0.281 | N | - |
| | volume | hie. | 0.540 | Y | |
| | | seq. | 0.534 | N | - |

# Averages of the coefficient of determination of tempo and volume

4. For tempo, the averages of two coefficients are rather similar. Namely, a sequential tension structures are useful for creating a musical rendition model.
5. For volume, the average of the coefficient used the hierarchical tension structures are better than that used the sequential ones.
6. Nonetheless, most coefficient values are rather small and vary widely.

| Coefficient of determination of tempo | | |
|---|---|---|
| Music | Tension | |
| | Hierarchical | Sequential |
| Sonata Pathétique | 0.232 | 0.208 |
| Nocturne in E-flat major | 0.238 | 0.238 |
| K.331 | 0.349 | 0.352 |
| K.545 | 0.355 | 0.333 |
| Average | 0.293 | 0.283 |

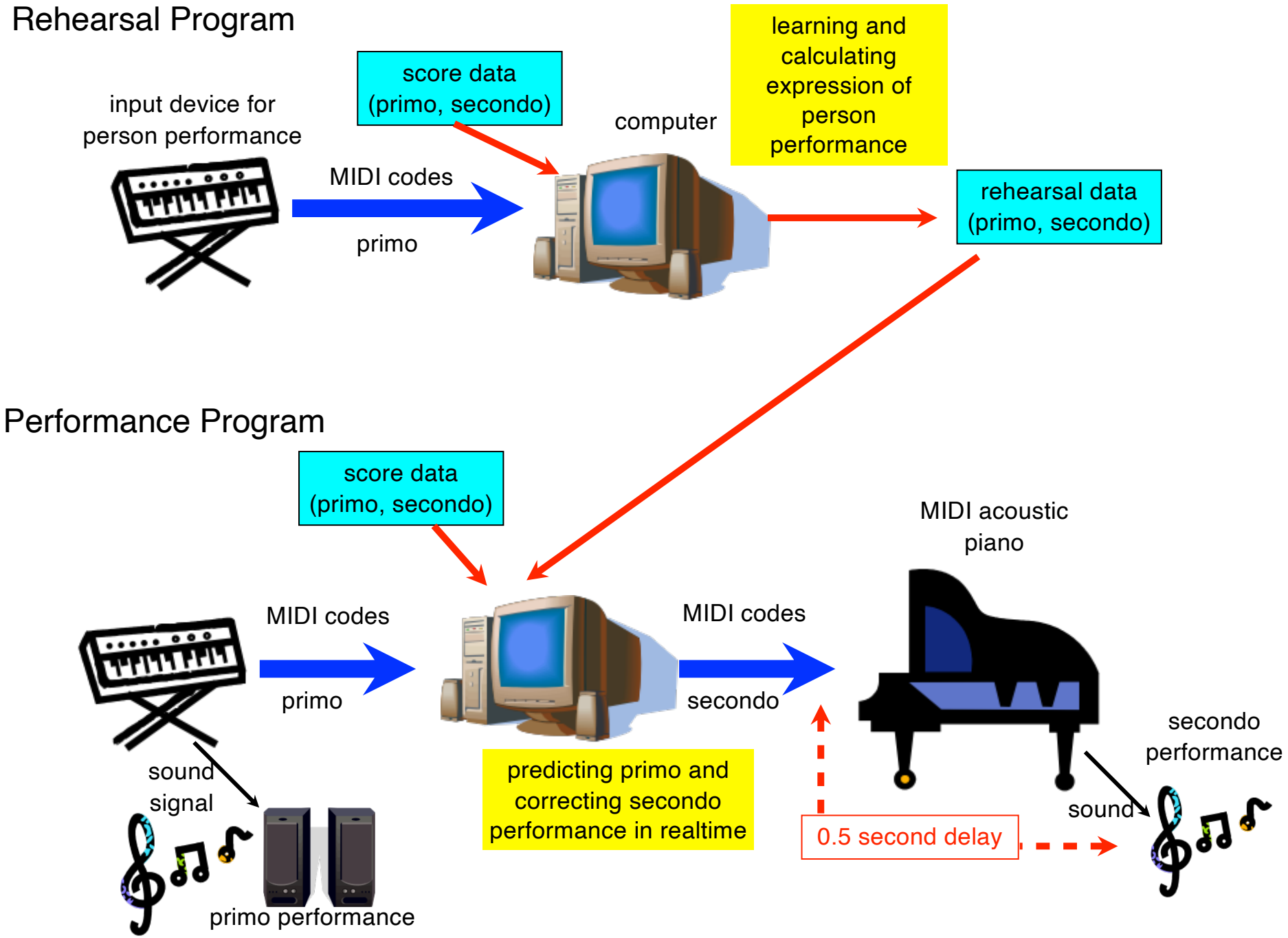
| Coefficient of determination of volume | | |
|---|---|---|
| Music | Tension | |
| | Hierarchical | Sequential |
| Sonata Pathétique | 0.290 | 0.211 |
| Nocturne in E-flat major | 0.450 | 0.423 |
| K.331 | 0.400 | 0.215 |
| K.545 | 0.233 | 0.023 |
| Average | 0.343 | 0.218 |

## Independent variables meaningful for rendition

7. Some tendency of the musical expression can be obtained, at least qualitatively. Namely, these independent variables can explain some trends of each music expression.
8. Some curious properties are also obtained.
   In especial, “piano”, which describes to play softly, affects not volume but tempo.

| Meaningful independent variables | | | | |
|---|---|---|---|---|
| | tempo | | volume | |
| Indep | Coeff | p | Coeff | p |
| Intercept | 57.4 | ** | 37.3 | ** |
| piano_start_M | -13.3 | * | | |
| forte_start_M | | | 13.6 | ** |
| slur_start_M | 5.17 | ** | | |
| slur_cont_M | 9.41 | * | | |
| slur_end_M | -3.76 | ** | | |
| cre_cont_M | | | 8.38 | ** |
| decre_cont_M | | | -9.97 | ** |
| staccato_M | -9.22 | ** | | |
| accent_M | 9.86 | ** | | |
| slur_cont_A | | | 5.88 | * |
| cre_start_A | | | 14.6 | ** |
| cre_cont_A | | | 12 | * |
| pedal_on | | | 4.58 | ** |
| pedal_off | -6.59 | ** | -3.8 | ** |
| tension | | | 4.5 | ** |

# Person-Computer Ensemble System



# 来年度の予定(希望)

現在の研究のさらなる発展
協調演奏システムのさらなる発展(Javaによる実装・実験が完成した)
演奏分析
検証の自動化
その他

# ゼミの内容，時間など

大学院進学希望者歓迎　(ただし現状では水谷は主指導教員にはなれません)

ゼミの内容は論文輪講，研究の進行状況の報告とそれに対するディスカッション
および教員の助言・指導が中心です．

曜日・時間は教官および学生の予定を考慮して定めます．

ゼミはまじめに出席しましょう．ゼミ以外の時間にもこまめに研究室に顔を出して
教員および他の研究室員と非公式のディスカッションを行うことが肝要です．