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School of Engineering

# MuSA.RT

Tonal Visualizations that Dance to the Rhythm of the Music

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## AGENDA

- What is MuSA.RT?
- Related Work
- MuSA.RT System Architecture**
  - Architectural Primitives in SAI
  - The Spiral Array Model
  - Real-Time MIDI Event Processing
  - Spiral Array Tonal Analysis Algorithms
  - Rendering
  - Camera Control
- Demonstration of MuSA.RT**
  - Different Patterns of Mozart's Rondos
  - J.S. Bach Prelude No.1 in C from the Well-Tempered Clavier
  - P.D.Q. Bach Prelude No.1,4,5,7 from the Short-Tempered Clavier
- Conclusions



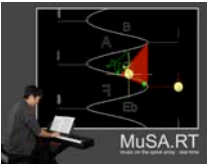

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## WHAT IS MuSA.RT?

MuSA.RT stands for *Music on the Spiral Array . Real Time.*  
 MuSA.RT is a real-time, interactive music visualization system that tracks and displays the trajectory of the tonal content and context of music.

It is both

- an *interactive art installation* that can convert musical performances to mathematically elegant graphics, and
- a *scientific tool for visualizing* the inner workings of tonal induction and tracking *algorithms.*

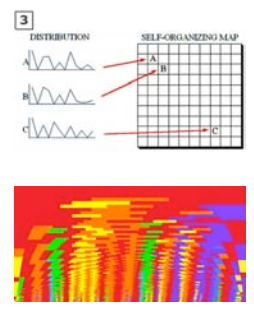
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## RELATED WORK: General Visualization

Example: Media Player Plugins





USC Viterbi School of Engineering RELATED WORK: Tonal Visualization




Toiviainen & Krumhansl (2003) "Measuring and modeling real-time responses to music: the dynamics of tonality induction." Perception 32(6):741-766.


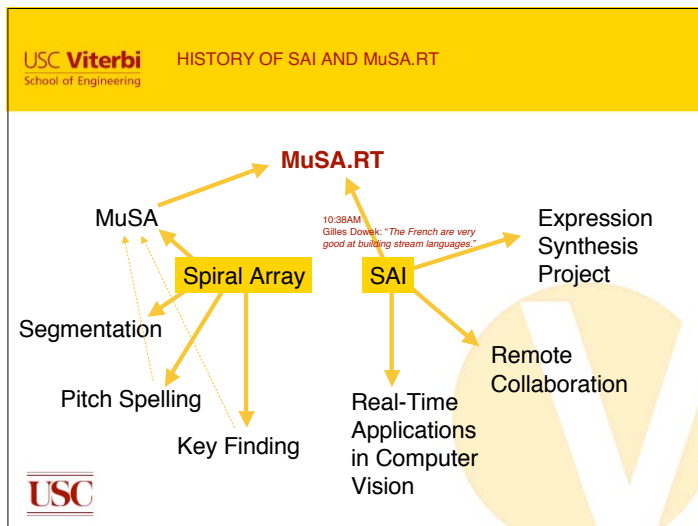
Sapp (2001) "Harmonic Visualizations of Tonal Music." In Proceedings of the International Computer Music Conference, pp. 423-430. Tonal Landscape Gallery: [ccrma.stanford.edu/~craig/keyscape](http://ccrma.stanford.edu/~craig/keyscape).



USC Viterbi School of Engineering MuSA – Music on the Spiral Array




Implemented by Yun-Ching Chen (2002)

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### PRIMITIVES OF SAI

**Streams** consisting of *volatile data*

**Cells** that serve as *processing units* (asynchronous parallel model)

**Sources** that serve as repositories of *persistent data*

**Pulses** that *synchronize structure* (time stamps, duration)  
 Active: volatile, flow down stream connections  
 Passive: persistent (dynamic), held in sources

(see François 2004)

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### ARCHITECTURAL MIDDLEWARE

Support architectural abstractions  
 Pulse, source, cell, etc.

Modular FlowScheduling Middleware (MFSM)  
 Open source project: [mfsm.SourceForge.net](http://mfsm.SourceForge.net)  
 C++, cross-platform (GNU compiler)

Base library  
 Functional modules  
 Documentation  
 Tutorials

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### MuSA.RT SYSTEM ARCHITECTURE

**Tonal Analysis**

- MIDI event processing
- Real-time CE algorithms
- Event processing
- Tonal data integration
- Spiral array, Virtual camera and other process parameters

**Interactive Rendering**

- Rendering
- Camera control
- Display
- User input
- Camera control

Performer → Pilot → Spectators

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### MuSA.RT: SYSTEM COMPONENTS

# MuSA.RT

USC Viterbi School of Engineering ONE SLIDE ON ESP

Pls: Elaine Chew & Alexandre François  
Students: Jie Liu & Aaron Yang

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USC Viterbi School of Engineering MuSA.RT SYSTEM ARCHITECTURE

USC Viterbi School of Engineering THE HARMONIC NETWORK (attributed to Euler, Riemann, Longuet-Higgins)

|     |     |     |    |    |    |    |    |     |     |
|-----|-----|-----|----|----|----|----|----|-----|-----|
|     | F#  | C#  | G# | D# | A# | E# | B# | F## | C## |
| G   | D   | A   | E  | B  | F# | C# | G# | D#  | A#  |
| Eb  | Bb  | F   | C  | G  | D  | A  | E  | B   | F#  |
| Cb  | Gb  | Db  | Ab | Eb | Bb | F  | C  | G   | D   |
| Abb | Ebb | Bbb | Fb | Cb | Gb | Db | Ab | Eb  | Bb  |

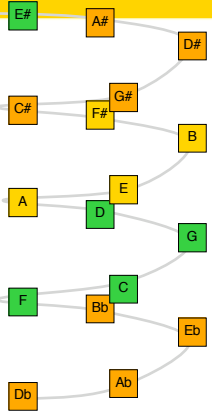
USC Viterbi School of Engineering THE HARMONIC NETWORK (attributed to Euler, Riemann, Longuet-Higgins)



|     |     |     |    |    |    |    |    |     |     |
|-----|-----|-----|----|----|----|----|----|-----|-----|
|     | F#  | C#  | G# | D# | A# | E# | B# | F## | C## |
| G   | D   | A   | E  | B  | F# | C# | G# | D#  | A#  |
| Eb  | Bb  | F   | C  | G  | D  | A  | E  | B   | F#  |
| Cb  | Gb  | Db  | Ab | Eb | Bb | F  | C  | G   | D   |
| Abb | Ebb | Bbb | Fb | Cb | Gb | Db | Ab | Eb  | Bb  |

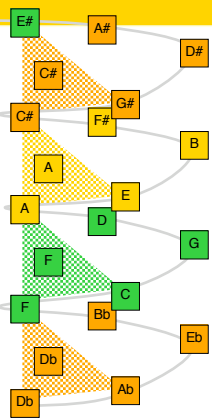
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USC Viterbi School of Engineering SPIRAL ARRAY: PART I



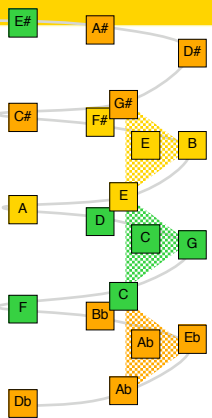
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USC Viterbi School of Engineering SPIRAL ARRAY: PART II

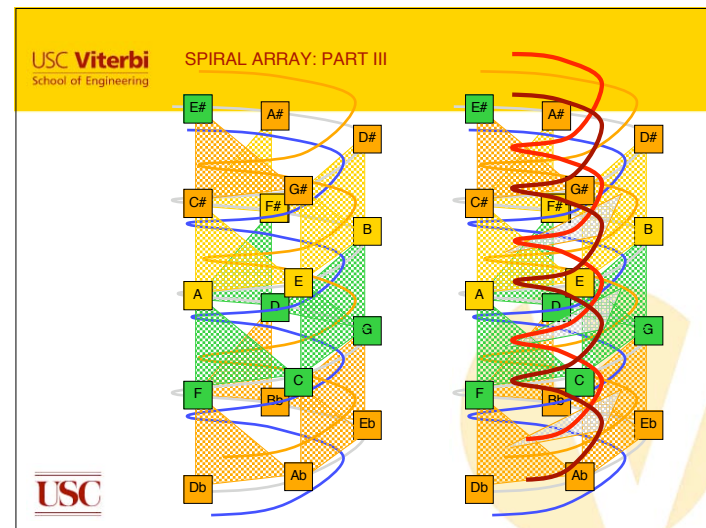
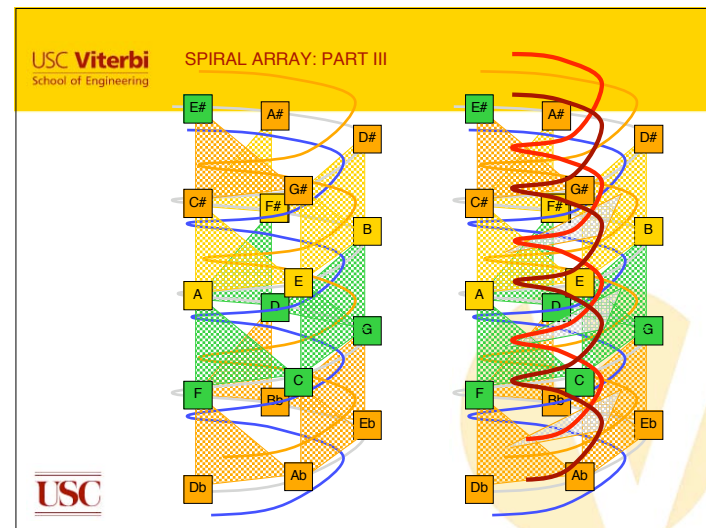
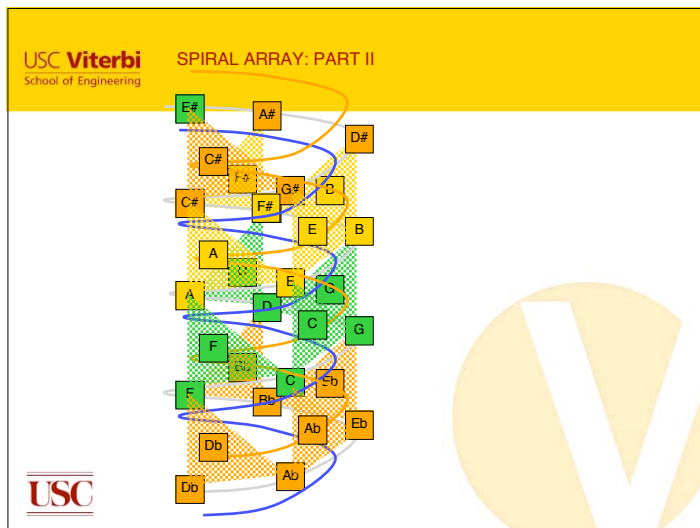
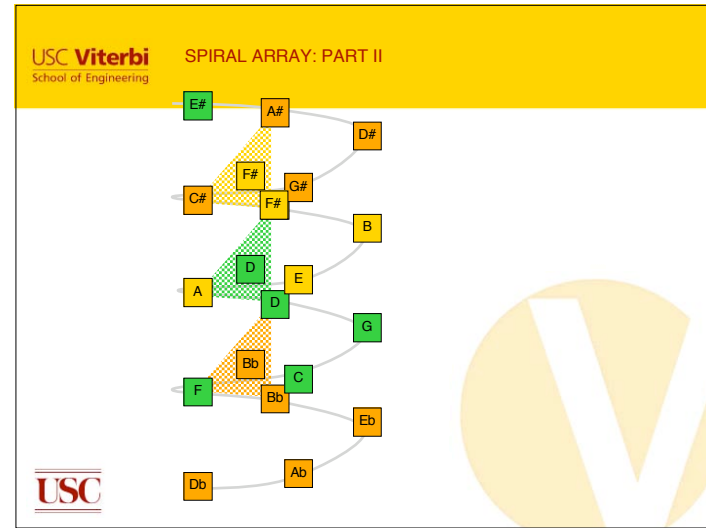
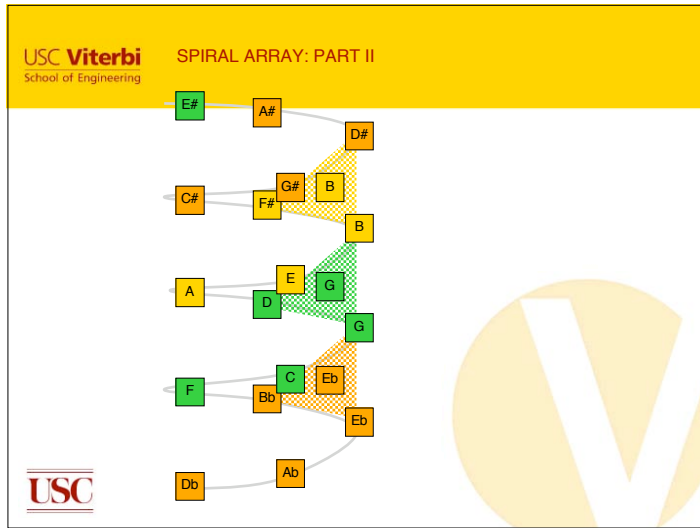


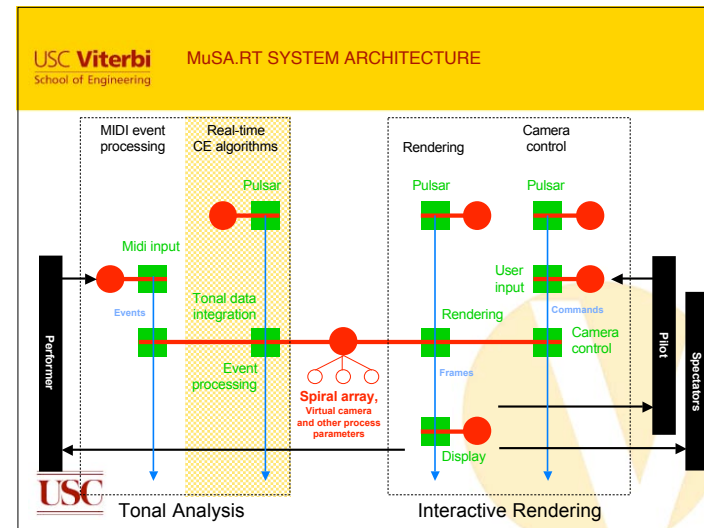
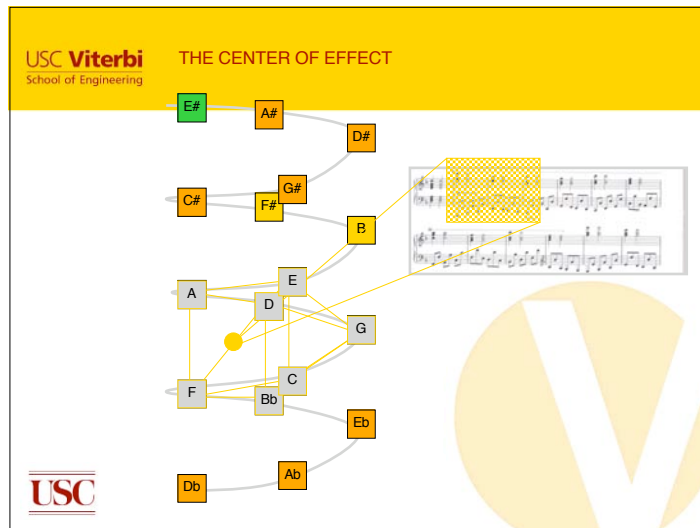
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USC Viterbi School of Engineering SPIRAL ARRAY: PART II



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USC Viterbi School of Engineering EQUATION FOR THE CENTER OF EFFECT

In this version of MuSA.RT, we use a c.e. generator that is a linear function that weights the most recent events more than distant events:

$$CE(t) = \alpha (CE \text{ of notes in current pulse}) + (1 - \alpha) CE(t-1)$$

We maintain two c.e.'s, one for long-term tonal structures, and one for local tonal patterns:

$$CE_1(t) = \alpha (CE \text{ of notes in current pulse}) + (1 - \alpha) CE_1(t-1)$$

$$CE_2(t) = \beta (CE \text{ of notes in current pulse}) + (1 - \beta) CE_2(t-1)$$

At present,  $\alpha$  and  $\beta$  are parameters that can be set by the user.

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USC Viterbi School of Engineering THE CENTER OF EFFECT

Serves as a summary point for tonal information

**Key finding:** Quickly converges to a region where its key representation is the closest one among all keys

Can be used for key-finding using nearest neighbor search for closest key representation (Chew, 2000/2001)

**Chord tracking:** For smaller windows, the nearest triad representation returns the closest triad to the pitch collection (Chew, 2000)

**Pitch spelling:** Can serve as a proxy for key or tonal context

Using the c.e., we can select pitch spellings that are contextually consistent using a nearest neighbor search for closest pitch name (Chew & Chen, 2003/2005)

**Tonal segmentation:** Difference between two consecutive c.e.'s can be used in tonal segmentation (Chew 2004/2005)

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USC Viterbi School of Engineering **ALGORITHMS USING THE CENTER OF EFFECT**

Suppose  $CE_2(t)$  is the long-term CE, that is,  $\square > \square$ .


**Key-finding**

$$Key(t) = \operatorname{argmin}_{key} |CE_2(t) - key|$$

**Chord-tracking**


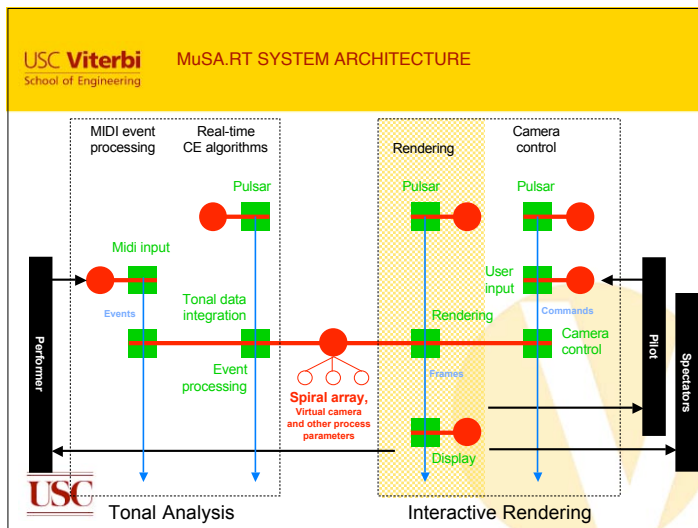
$$Chord(t) = \operatorname{argmin}_{triad} |CE_1(t) - triad|$$

**Pitch spelling**

$$Pitchname(t,j) = \operatorname{argmin}_{names(pitch\ j)} |CE_1(t) - name(pitch\ j)|$$


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USC Viterbi School of Engineering **VISUAL OBJECTS**

closest triad lights up

triad label


local c.e.

longterm c.e.

closest key is pulsating orb (size proportional to dist)


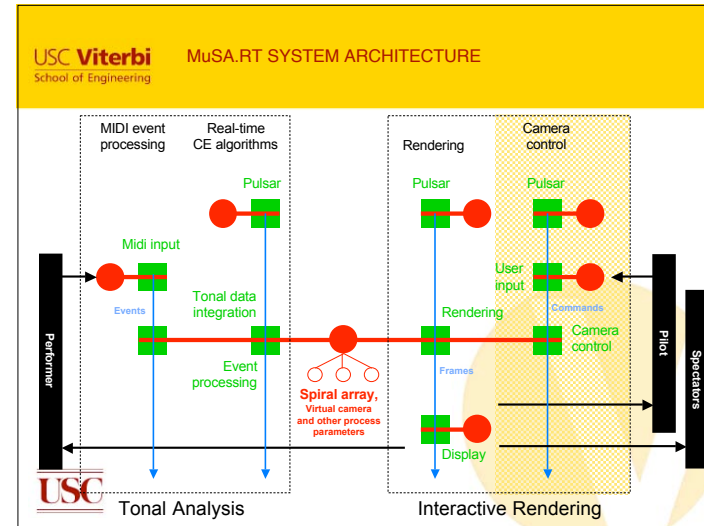
key label

only pitch spiral is shown

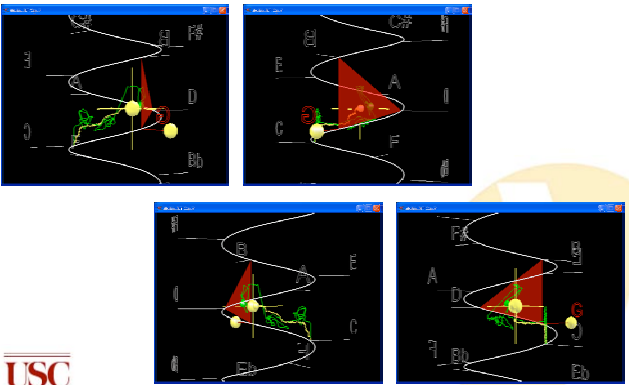

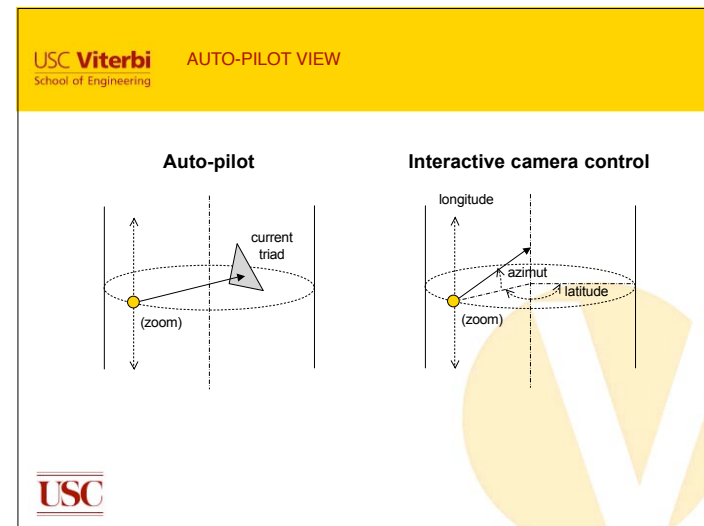


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


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USC Viterbi School of Engineering MANUAL VIEW CONTROL: Bach's *Prelude No.1 in C*, b.1-3

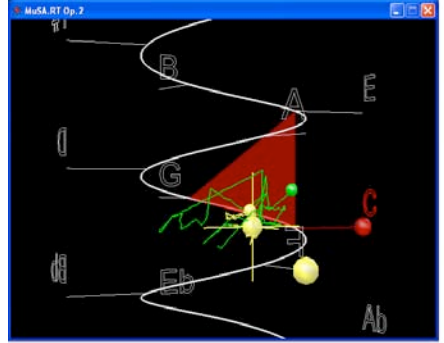

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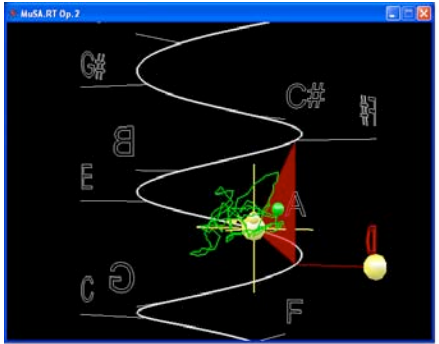

**Conclusions**

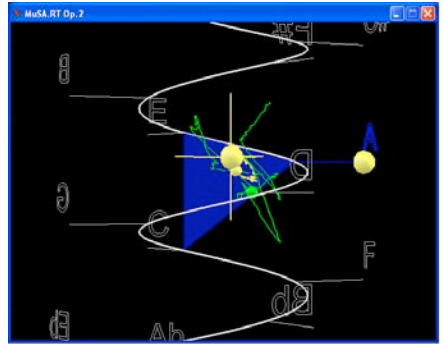

USC Viterbi School of Engineering PATTERNS: Mozart *Rondo* K.494

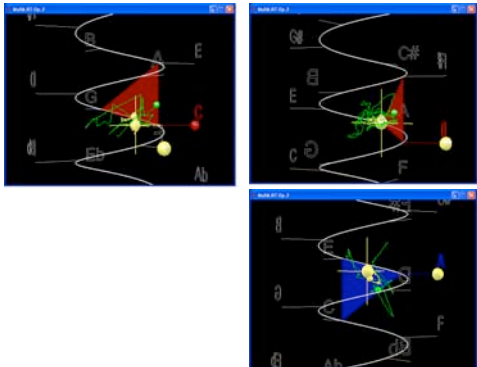
USC Viterbi School of Engineering PATTERNS: Mozart *Rondo* K.485

USC Viterbi School of Engineering PATTERNS: Mozart *Rondo* K.511

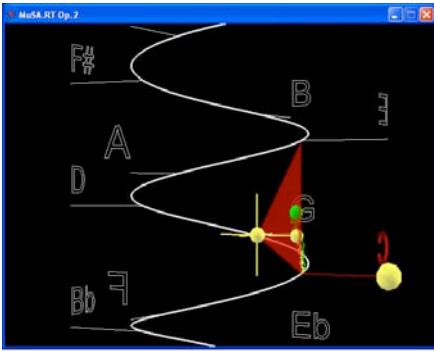
USC Viterbi School of Engineering COMPARE PATTERNS: Mozart's Rondos



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This slide displays three small windows, each showing a tonal visualization. The windows are arranged in a 2x2 grid with the bottom-right cell empty. Each window features a white sine wave on a black background, with various musical notes and colored shapes (red, green, blue) overlaid to represent tonal patterns. The notes include F, A, E, G, C, Bb, and F. The USC logo is in the bottom-left corner.

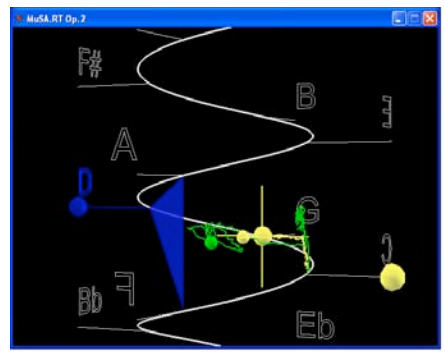
USC Viterbi School of Engineering TRAJECTORY: Bach *Prelude No. 1 in C* from the WTC I, b.1



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This slide shows a single large window titled "MuSA.RT Op. 2" displaying a tonal trajectory. A white sine wave is shown on a black background, with musical notes F#, A, D, Bb, F, B, G, and Eb labeled. A red triangle and a yellow sphere are positioned on the wave, connected by a green line, representing the trajectory of the music. The USC logo is in the bottom-left corner.

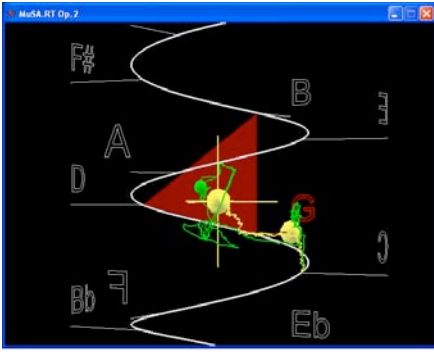
USC Viterbi School of Engineering TRAJECTORY: Bach *Prelude No. 1 in C* from the WTC I, b.2



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This slide shows a single large window titled "MuSA.RT Op. 2" displaying a tonal trajectory. A white sine wave is shown on a black background, with musical notes F#, A, D, Bb, F, B, G, and Eb labeled. A blue triangle and a yellow sphere are positioned on the wave, connected by a green line, representing the trajectory of the music. The USC logo is in the bottom-left corner.

USC Viterbi School of Engineering TRAJECTORY: Bach *Prelude No. 1 in C* from the WTC I, b.3



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This slide shows a single large window titled "MuSA.RT Op. 2" displaying a tonal trajectory. A white sine wave is shown on a black background, with musical notes F#, A, D, Bb, F, B, G, and Eb labeled. A red triangle and a yellow sphere are positioned on the wave, connected by a green line, representing the trajectory of the music. The USC logo is in the bottom-left corner.

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TRAJECTORY: J.S.Bach's *Prelude No. 1 in C*, b.1-3

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ABOUT P.D.Q. BACH

painting © Franz Romanesohn, Konfirmation

**The Short-Tempered Clavier**  
 Preludes and Fugues in All the Major and Minor Keys Except for the Really Hard Ones (S. 3.14159, easy as)

Composed for the modern Pianoforte by P.D.Q. Bach (1807-1742)?

Edited for post-modern fingers by Professor Peter Schickele

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EXAMPLE: P.D.Q.Bach's *Prelude I*

**The Short-Tempered Clavier**  
 Preludes and Fugues in All the Major and Minor Keys Except for the Really Hard Ones (S. 3.14159, easy as)

Duration: c. 30' Composed for the modern Pianoforte by P.D.Q. BACH (1807-1742)? Edited for post-modern fingers by Professor Peter Schickele

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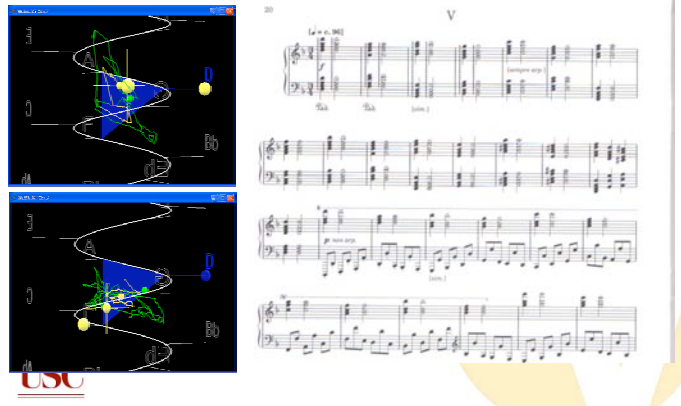
COMPARE: J.S.Bach vs P.D.Q.Bach

J.S.Bach

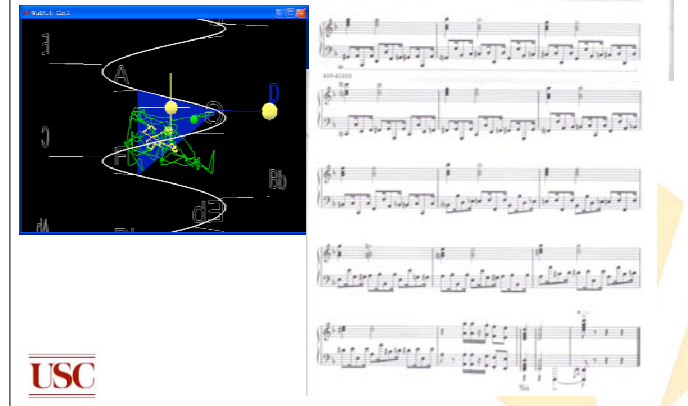
P.D.Q.Bach

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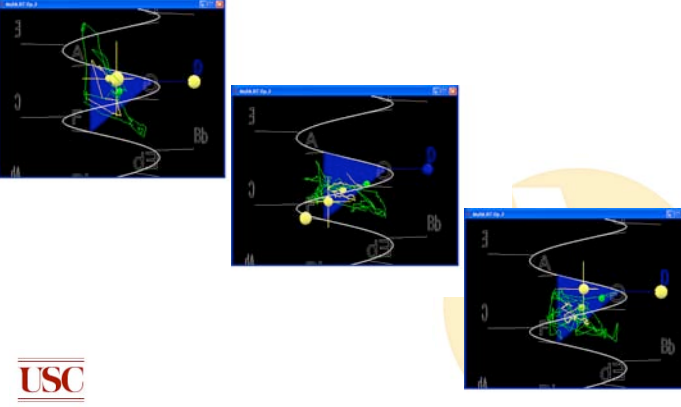
USC Viterbi School of Engineering VARIATIONS: P.D.Q.Bach *Prelude V*



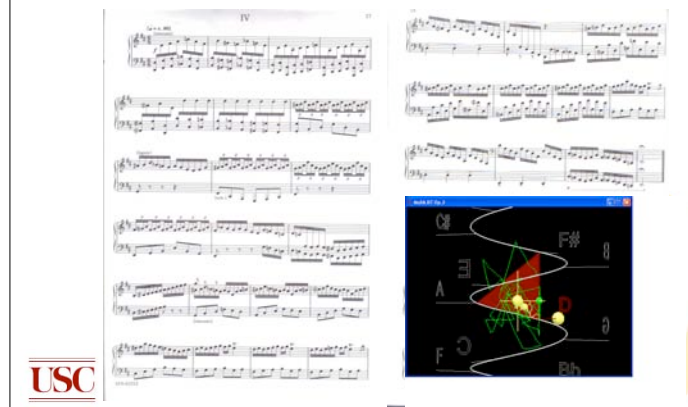
USC Viterbi School of Engineering (Cont...)



USC Viterbi School of Engineering COMPARE: P.D.Q.Bach *Prelude V*



USC Viterbi School of Engineering VARIATIONS: P.D.Q.Bach *Prelude IV*



USC Viterbi School of Engineering COMPARE: P.D.Q.Bach *Prelude IV*

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USC Viterbi School of Engineering VARIATIONS: P.D.Q.Bach *Prelude VII*

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USC Viterbi School of Engineering COMPARE: P.D.Q.Bach *Prelude VII*

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**USC Viterbi** COMMENTS AND CONCLUSIONS  
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**Advantages:**

- Real-time analysis
- Visual assessment of style.
- Visual assessment of similarity.
- Visual map of artistic expression.

**Challenges:**

- Visualizing only 3-note chords (triads) is limiting.
- Real-time segmentation for contextual changes.
- Dynamically (automatically) changing  $\alpha$ 's,  $\beta$ 's, ...

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