

Music Understanding and the Future of Music

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Why Computers and Music?

- Music in every human society!
- Computers are everywhere!
- Music is technological!
- Computing can make music:
 - More Fun
 - More Available
 - Higher Quality
 - More Personal



My Background

- Always interested in math and music and making things
- Trumpet player since age 11
- Discovered synthesizers in high school
- Discovered computers about the same time
- Discovered computer music in college
- Musical Acoustics with Art Benade
- Research motivated by musical experience:
 - Computers as performers
 - Expressive programming languages for music
 - Audacity Audio Editor (co-creator)

Overview

- Introduction

- How Is Computation Used in Music Today?

- New Capabilities:

 - What Can Computers Do Tomorrow?

- What Will Music Be Like in the Future?

How Is Computation Used in Music Today?



Indabamusic.com



http://venturebeat.com/













making-music.blogspot.com

iLike / Rate artists

Hi Sebastian A. in partnership with

Tell us which artists you like

We'll recommend you new music and calculate your music compatibility with your friends on iLike. The more artists you rate, the b

 Thievery Corporation <input type="button" value="iLike"/>	 Carrie Underwood <input type="button" value="iLike"/>	 Keith Urban <input type="button" value="iLike"/>	 Coldplay <input type="button" value="iLike"/>	 Beyoncé <input type="button" value="iLike"/>
<input type="button" value="I like this artist"/>				
 Leona Lewis <input type="button" value="iLike"/>	 Radiohead <input type="button" value="iLike"/>	 The Beatles <input type="button" value="iLike"/>	 Kelly Clarkson <input type="button" value="iLike"/>	 Pearl Jam <input type="button" value="iLike"/>

Music Computation Today

Production: digital recording, editing, mixing

- Nearly all music production today...
 - Records audio to (digital) disk
 - Edit/manipulate audio digitally
 - Equalization
 - Reverberation
 - Convert to media:
 - CD
 - MP3
 - Etc.



protools.com

Music Computation Today

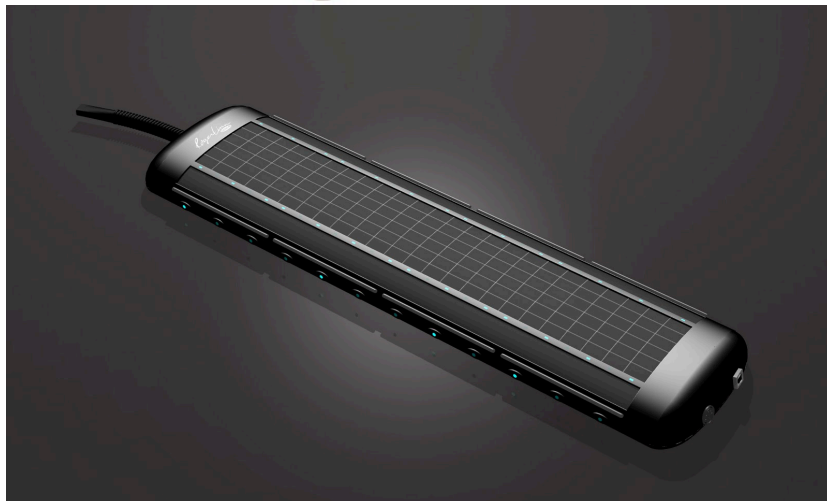
Musical Instruments: synthesizers and controllers



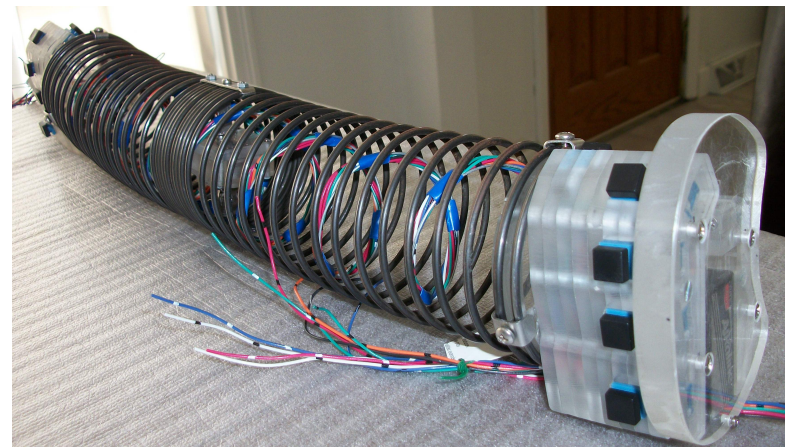
Synthesizer (Solaris)



Drum Machine (Yamaha)



Linnstrument (Roger Linn)



Sonic Spring (Tomas Henriques)

Music Computation Today

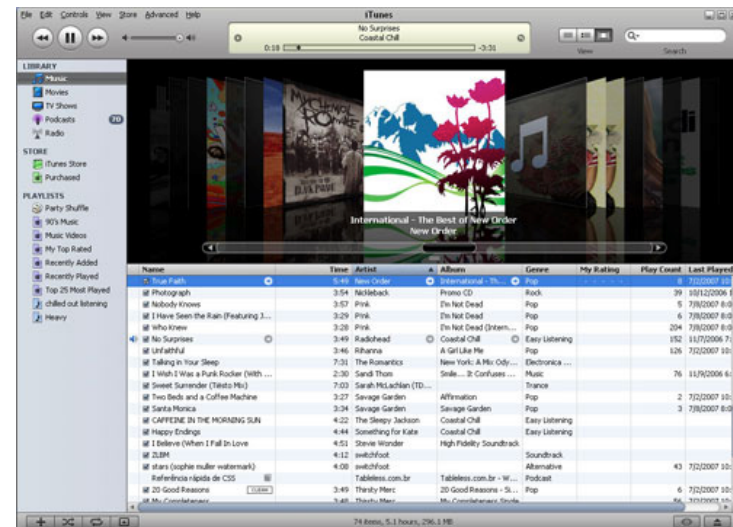
Distribution: compression, storage, networks



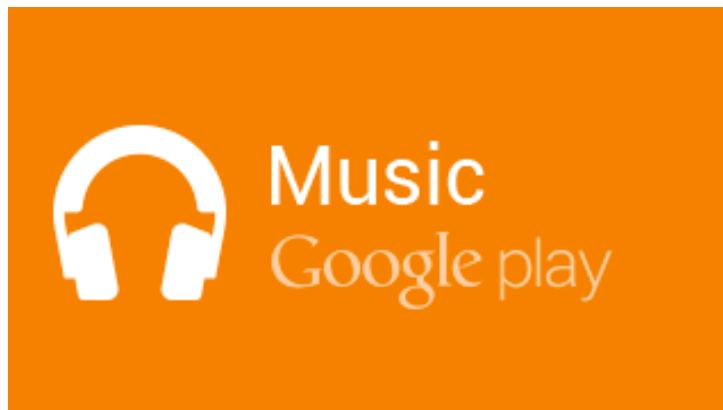
Napster



Apple iPod



Apple iTunes

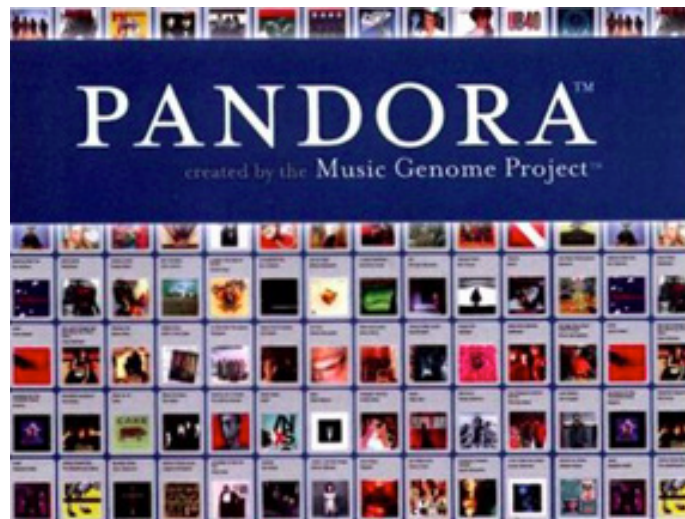


Music Computation Today

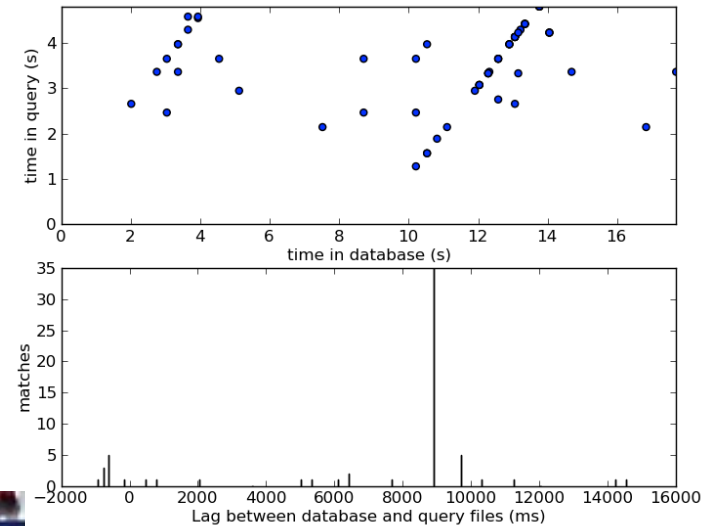
Search, recommendation, music fingerprinting



Google Music China



Pandora Music Recommendation



Music Fingerprinting

Overview

- Computer Music Introduction
 - How Is Computation Used in Music Today?
-
- New Capabilities:
 What Can Computers Do Tomorrow?
 - What Will Music Be Like in the Future?

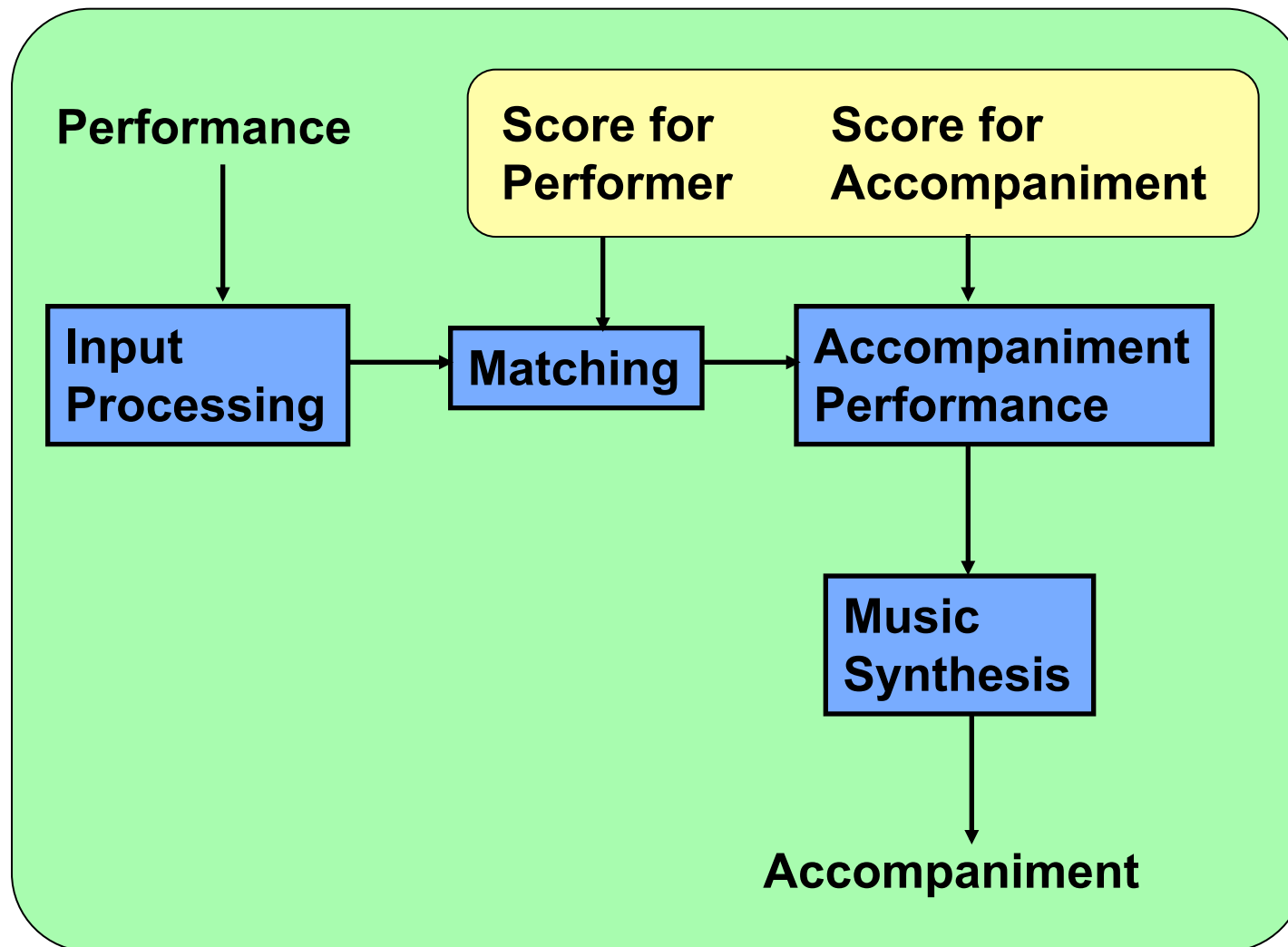
New Capabilities: What Can Computers Do Tomorrow?

- Computer accompaniment
- Style classification
- Score alignment
- Onset detection
- Sound synthesis

Accompaniment Video



Computer Accompaniment

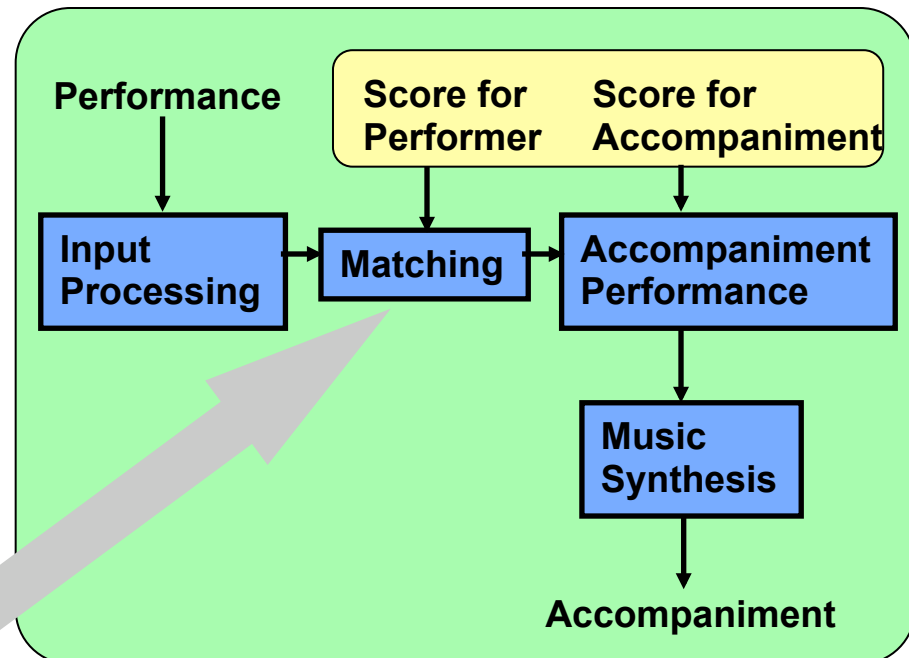


Computer Accompaniment

Performance →

Score →

	A	B	A				
A	1	1					
B	1	2	2				
B	1	2	2				
A	1	2	3				
C		2	3				
B			3				
G							



Dynamic Programming, plus ...

On-line, column-by-column evaluation

Windowing for real-time evaluation

Heuristics for best-yet matching

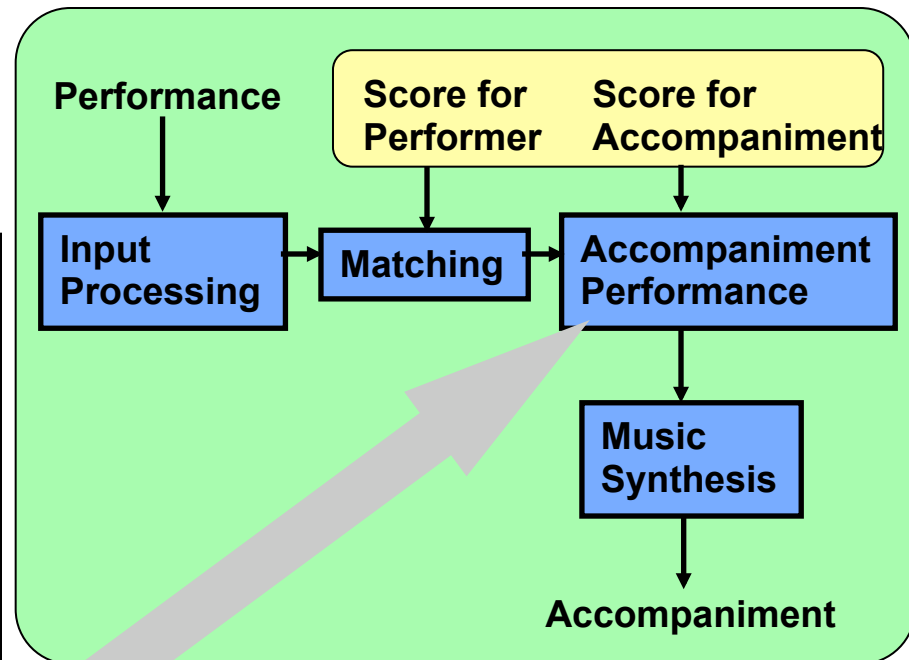
Penalty for skipping notes

Computer Accompaniment

Rule-based system:

E.g. If matcher is confident and accompaniment is ahead $< 0.1s$, stop until synchronized.

If matcher is confident and accompaniment is behind $< 0.5s$, speed up until synchronized.



Vocal Accompaniment

- Lorin Grubb's Ph.D. (CMU CSD)
- Machine learning used to:
 - Learns what kinds of tempo variation are likely
 - Characterize sensors
 - When is a notated G sensed as a G#?
- Machine learning necessary for good performance

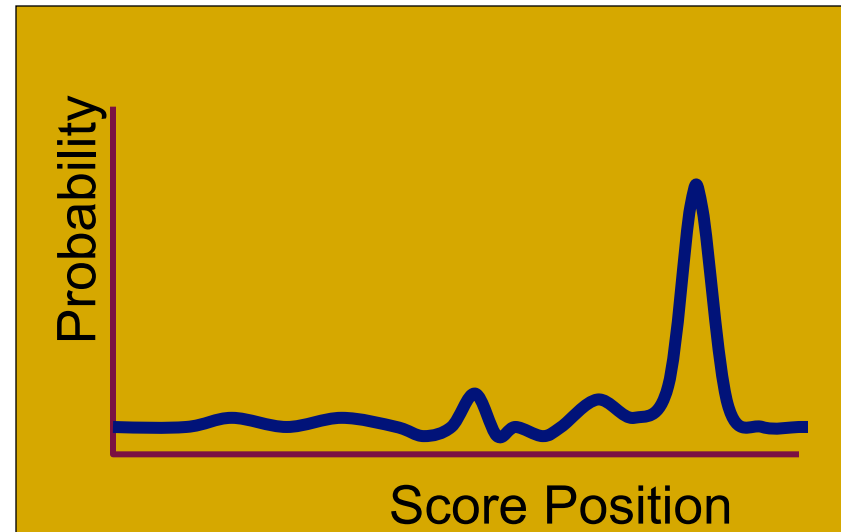


Vocal Accompaniment



How It Works

- Score position modeled as a probability density function
- Bayesian update rule:
 $P(s|o) \propto P(o|s)P(s)$
- $P(o|s)$ is e.g. "probability of observing pitch G if the score says play an A."
Simple statistics on labeled training data.
- Prior $P(s)$ by fast *convolution* with a log normal (describes tempo and tempo variation)



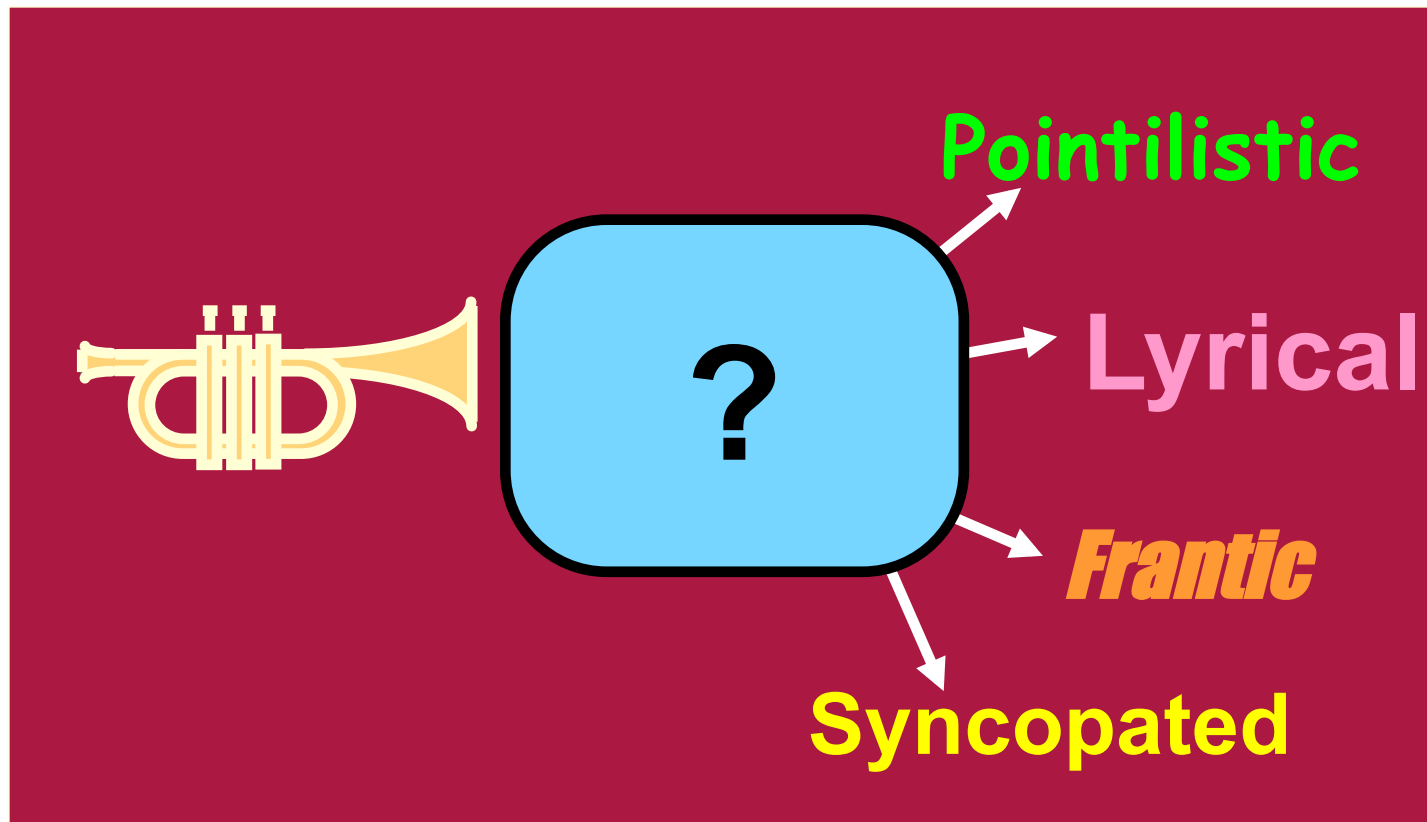
Commercial Implementation



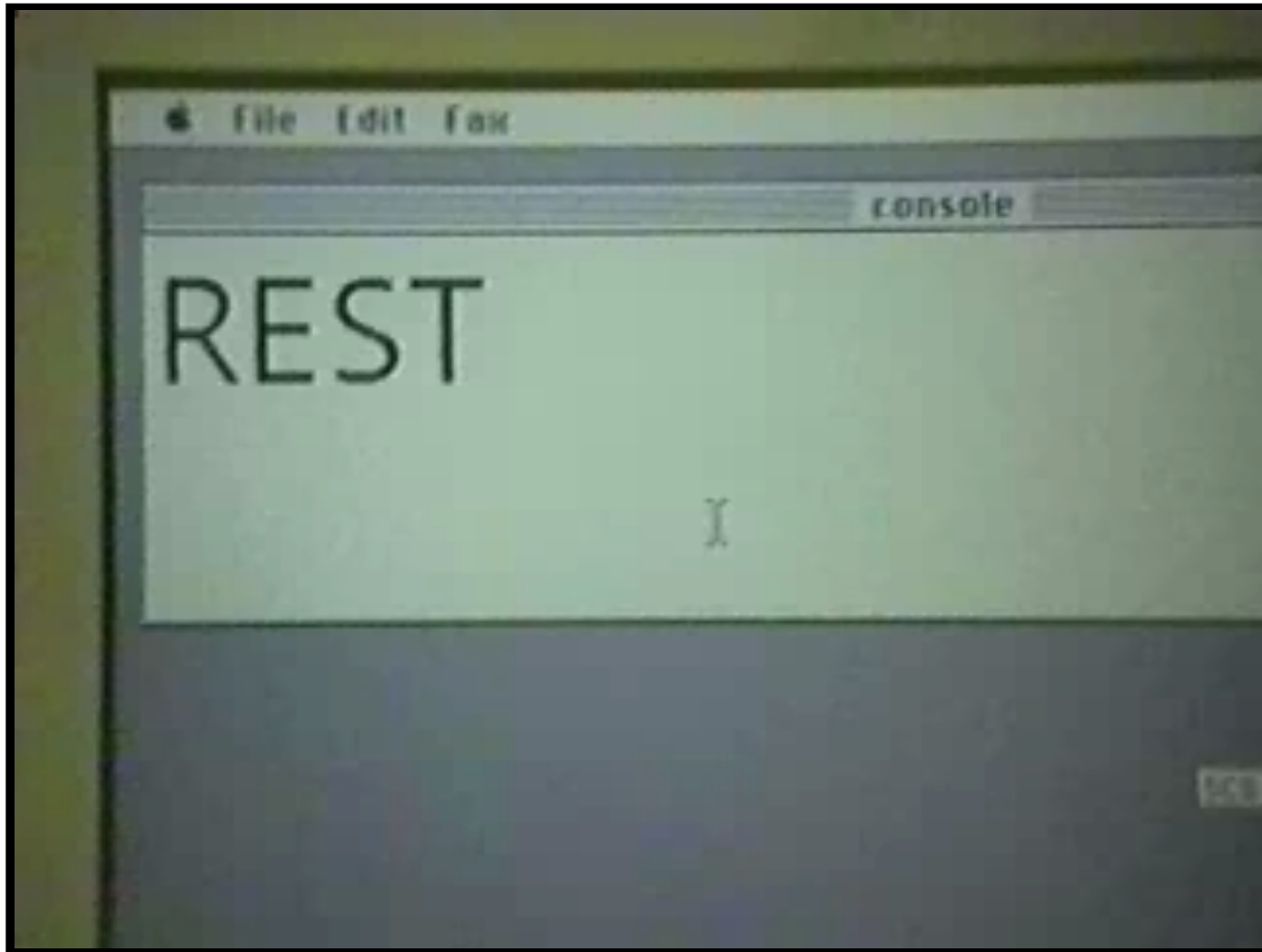
rtsp://qt.partner-streaming.com/makemusic/wm_03_L.mov

rtsp://qt.partner-streaming.com/makemusic/wm_04_L.mov

Style Classification: Listening to Jazz Styles



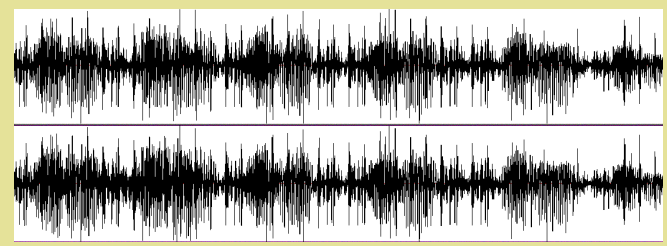
Jazz Style Recognition



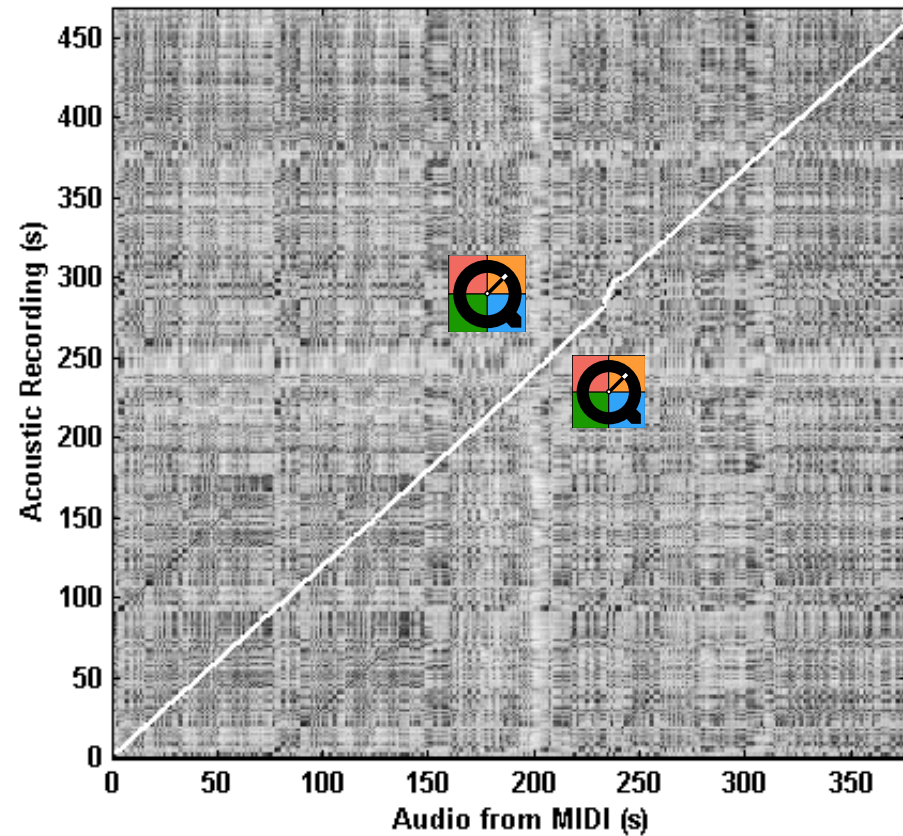

Techniques

- Extract features from audio:
 - Note density
 - Mean & Std. Dev. of pitch range
 - Mean & Std. Dev. of pitch intervals
 - Silence vs. Sounding ("duty factor")
 - ... and many more
- Features over 5-second windows
- Standard Classifiers (Naive Bayes, Linear, Neural Net)

Polyphonic Audio-to-Score Alignment



VS



Audacity Editor with Automatic Audio-to-MIDI Alignment

The screenshot displays the Audacity Editor interface for a project titled "Haydn_Symphony No.94_1st mvmt". The top toolbar includes playback controls (stop, play, record, previous, next), editing tools (select, copy, paste, delete, undo, redo), and volume controls for Mix and Input. The transport bar shows a time scale from 0 to 2:00, with a playhead at approximately 1:00.

The main workspace is divided into two tracks:

- Audio Track:** Labeled "Haydn_Sym" (Stereo, 44100Hz, 32-bit float). It displays two channels of audio waveforms. The left channel is muted, and the right channel is active. The amplitude ranges from -1.0 to 1.0.
- Note Track:** Labeled "Note Track". It shows a piano roll with 16 piano keys (numbered 1-16) on the vertical axis. The horizontal axis represents time. Colored horizontal bars represent MIDI notes, which are automatically aligned with the audio waveforms above. The notes are color-coded by piano: 1-4 (red), 5-8 (orange), 9-12 (yellow), 13-16 (green).

The bottom status bar provides project settings:

- Project Rate (Hz): 44100
- Selection Start: 00 h 00 m 55.610 s
- End: 00 h 00 m 00.000 s
- Length: 00 h 00 m 00.000 s
- Audio Position: 00 h 00 m 00.000 s

A tooltip at the bottom left reads "Click and drag to select audio".

Intelligent Audio Editor

- This excerpt is included in the audio examples:

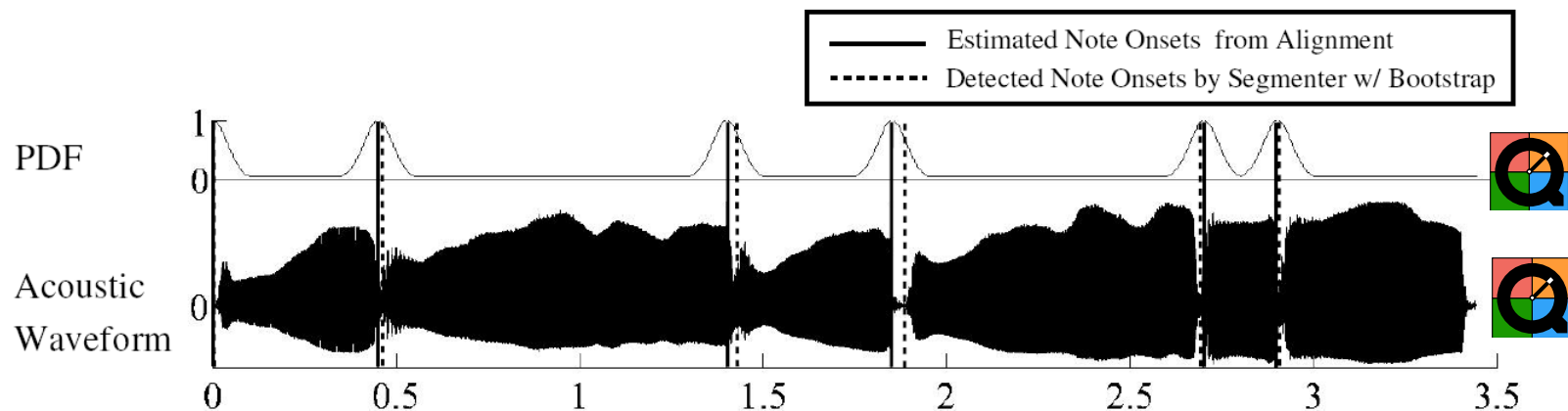


- Before:  After: 

Finding Note Onsets

(How to segment music audio into notes.)

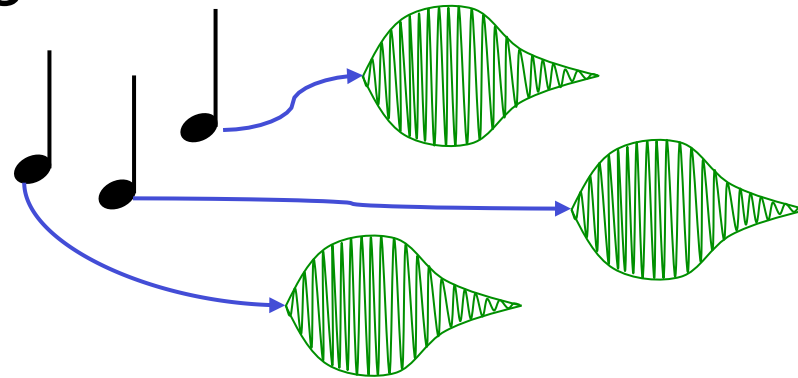
- Not all attacks are clean
- Slurs do not have obvious (or fast) transitions
- We can use score alignment to get a rough idea of where the notes are (~1/10 second)
- Then, machine learning can create programs that do an even better job (bootstrap learning).



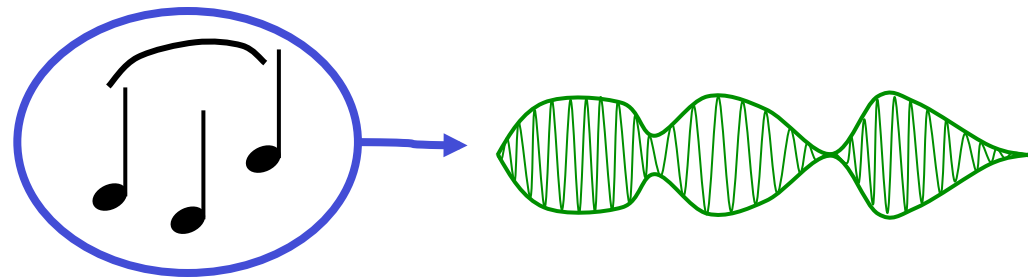
Expressive Performance

Phrase-based Synthesis

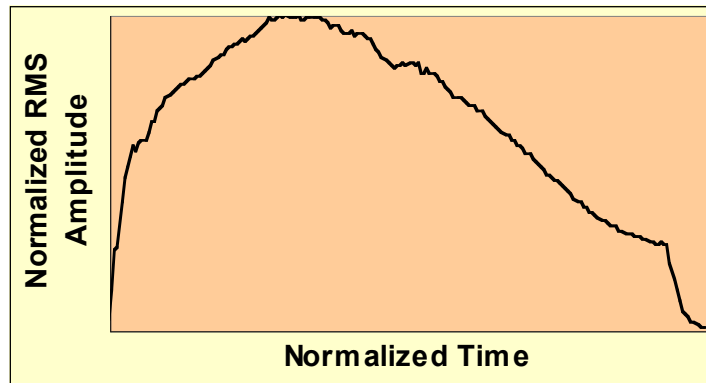
Note-by-Note Synthesis



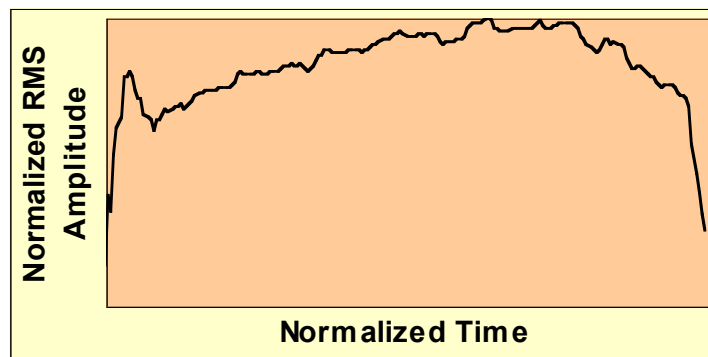
Phrase-based Synthesis



Example Envelopes








Tongued
Note



Slurred
Note

Synthesis Examples

- Good trumpet sounds, mechanically performed: 
- Same sounds, but performed with AI-based model of trumpet performance: 
- Another example: 
- Trumpet example from Ning Hu's thesis: 
- Bassoon example from Ning Hu's thesis: 

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Human Computer Music Performance

- OPPORTUNITY
 - State-of-the-art computer music systems for popular music performance
 - *Autonomous Intelligent Machine Musicians*

Example

- Suppose you want to get together and play music ... BUT, you're missing a *bass* player.



credit: Green Day

What Research Is Needed?

- Synchronization
 - Signal processing
 - Machine learning
 - Human interface
- Digital Music Display
 - Representation issues
- Improvisation
 - Models of style
- Sound Production
 - Phrase-based synthesis?
- Modularity/Systems issues
 - Real-time systems
 - Software architecture
- Interaction
 - HCI

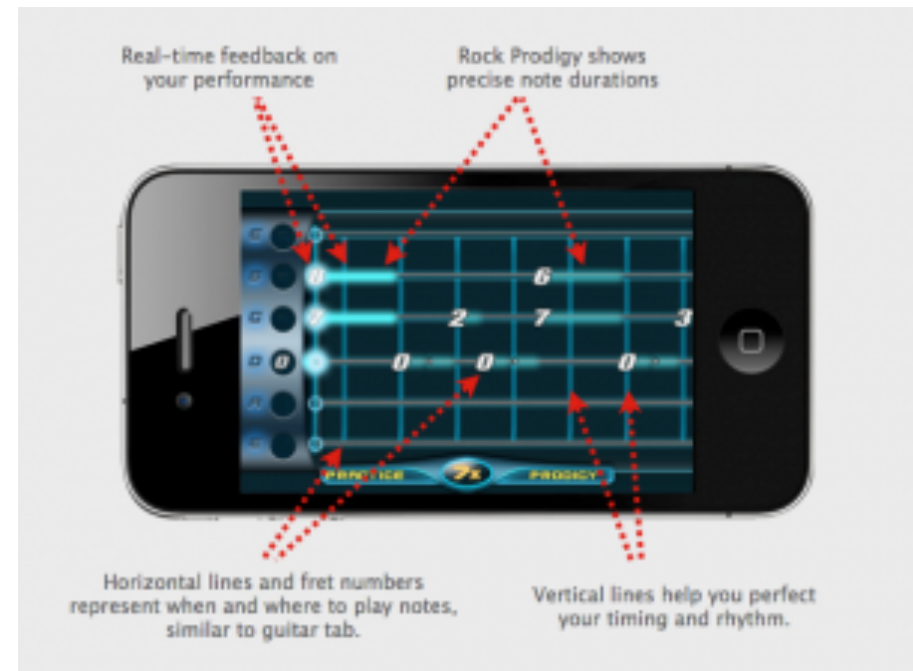


Is There a Market? What's the Impact?

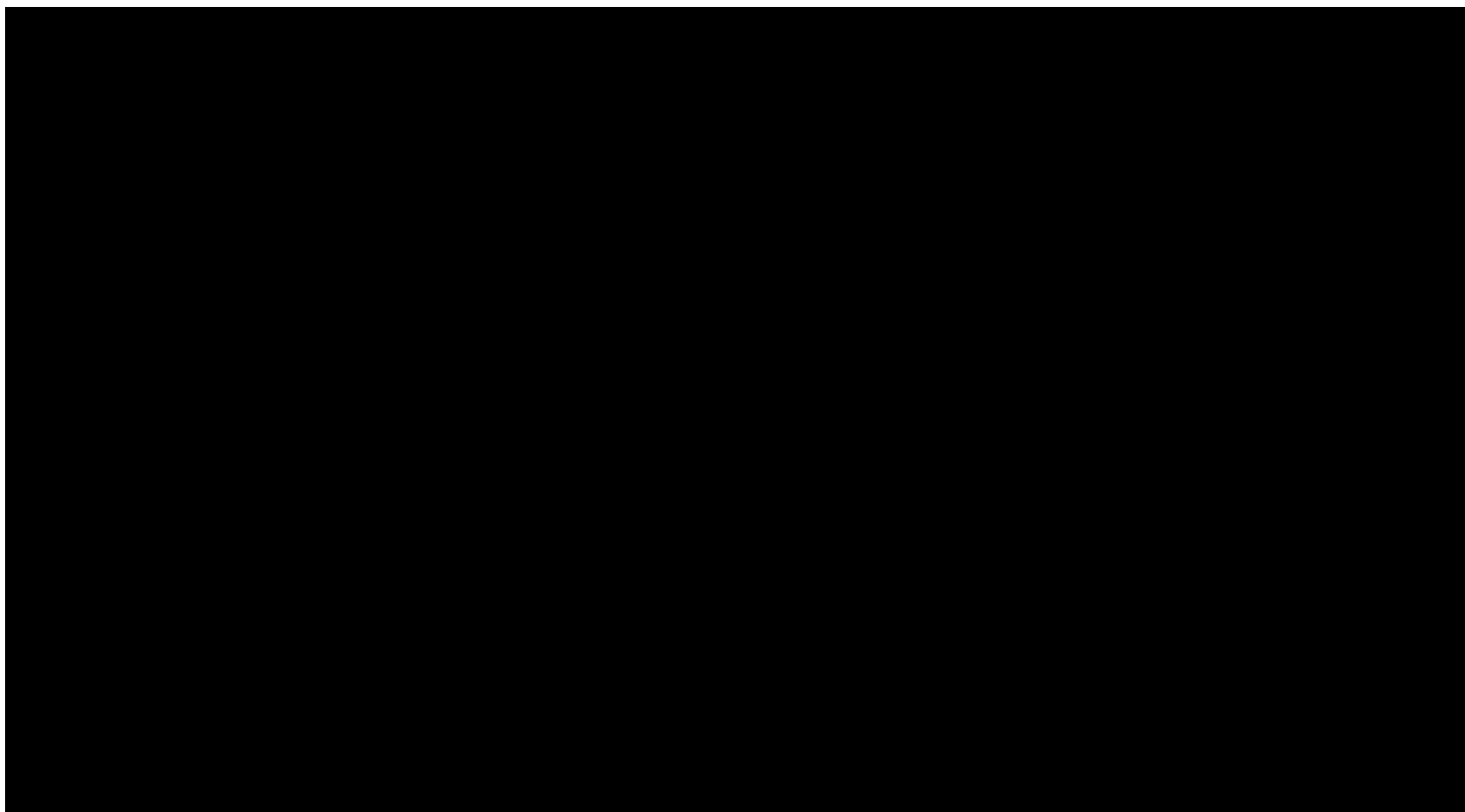
- \$8B annual US music sales
 - *Excluding* recordings, education, performances
- 5 million musical instruments per year
- Performance revenue is on the order of \$10B
- Recording revenue is similar; order of \$10B
- Approximately 1/2 of all US households have a practicing musician
- ... so *very roughly* \$10+B and 100M people!

Rock Prodigy

- Guitar Hero for Real Guitars
- Game design, content, animation, etc. by others
- (Play [Video](#))



Rock Prodigy



- **Unsolicited comment: "The best part about it is polyphonic pitch detection"**

An Example



Arrangements: Flexibly Adapting Music Data for Live Performance

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Andrew Russell

Carnegie Mellon University

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1

Another Application: Internet Drum Circle

- Latency is key:



OK




Shakers with 0.1s delay



- Can computers
 - Play drums?
 - Lead humans to keep it interesting 24x7?
 - Help keep the beat steady?

Online, collaborative development of creative content is already here...



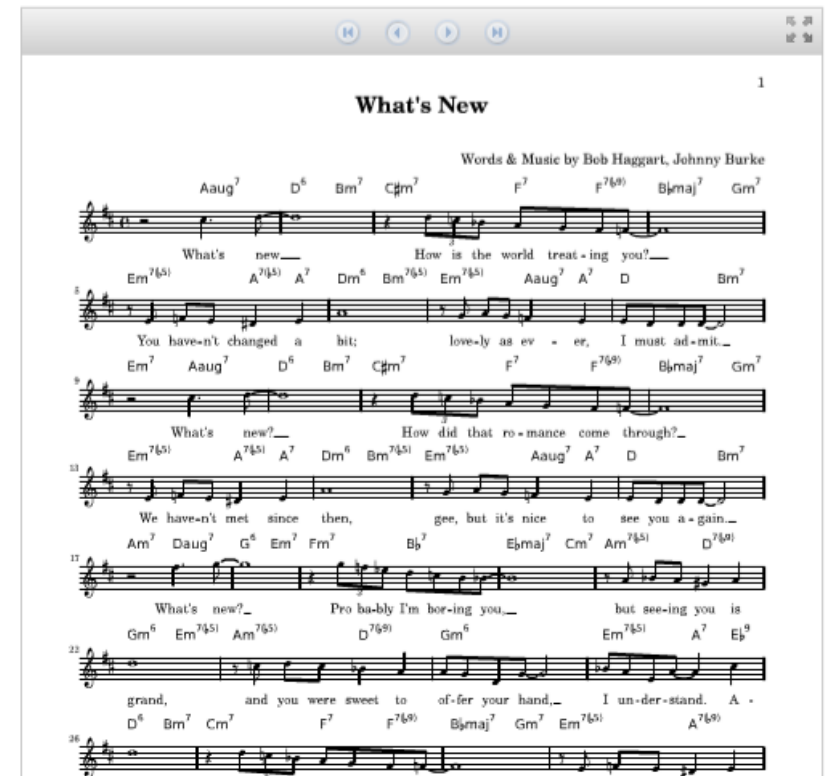
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lead sheets | artists | forum

C Eb Bb VERSION↑ PUBLISH

What's New

Music by [Bob Haggart](#)
 Words by [Johnny Burke](#)
 Performed by [Frank Sinatra](#), [Helen Forrest](#)



What's New 1

Words & Music by Bob Haggart, Johnny Burke

Aaug⁷ D⁶ Bm⁷ C#m⁷ F⁷ F^{7(b9)} Bbmaj⁷ Gm⁷

What's new_ How is the world treat-ing you?_

Em^{7(b5)} A^{7(b5)} A⁷ Dm⁶ Bm^{7(b5)} Em^{7(b5)} Aaug⁷ A⁷ D Bm⁷

You have-n't changed a bit; love-ly as ev - er, I must ad-mit_

Em⁷ Aaug⁷ D⁶ Bm⁷ C#m⁷ F⁷ F^{7(b9)} Bbmaj⁷ Gm⁷

What's new?_ How did that ro-mance come through?_

Em^{7(b5)} A^{7(b5)} A⁷ Dm⁶ Bm^{7(b5)} Em^{7(b5)} Aaug⁷ A⁷ D Bm⁷

We have-n't met since then, gee, but it's nice to see you a-gain_

Am⁷ Daug⁷ G⁶ Em⁷ Fm⁷ Bb⁷ Ebmaj⁷ Cm⁷ Am^{7(b5)} D^{7(b9)}

What's new?_ Pro ba-bly I'm bor-ing you_ but see-ing you is

Gm⁶ Em^{7(b5)} Am^{7(b5)} D^{7(b9)} Gm⁶ Em^{7(b5)} A⁷ Eb⁹

grand, and you were sweet to of-fer your hand_ I un-der-stand. A -

D⁶ Bm⁷ Cm⁷ F⁷ F^{7(b9)} Bbmaj⁷ Gm⁷ Em^{7(b5)} A^{7(b9)}

- ✦ Edit this sheet
- ✦ MusicXML
- ✦ MuseScore

Transpose
Page Format

Published by Musicdad
 on June 22, 2013
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Similar sheets

- When I Take My Sugar To Tea
- Chicago
- That Lucky Old Sun
- Sunday, Monday or Always
- After You've Gone

Genre
jazz

Media

■ stop



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Statistics

- 258 views

What Will People Do With HCMP?

- Practice with virtual bands.
- Create their own arrangements.
- Post machine-readable music online, share.
- Blend conventional performance with algorithmic composition, new sounds, new music.
- Robot performers.
- Eventually ... new art forms
- Think of the electric guitar, drum machine in music, camera in visual art, ...

Conclusion

- Automating Music Understanding (and Human Computer Music Performance) will *enrich musical experiences* for millions of people, including both amateurs and professionals.
- If we build computers that use understanding and intelligence to perform popular music, *great music will be made.*
That is the future of music performance.