

電腦音樂淺說

鄭士康
台大電機系/電信所/網媒所

綱要

- 簡介
- 電腦與音樂呈現
- 電腦與音樂創作
- 電腦與音樂聆聽
- 電腦與互動藝術
- 結語

藝術

藝術是一種有意的人為活動及其作品，這些活動及其作品無論是模仿自然界的事物，或創造形式，或表達經驗，都能表現出作者的思想與感情，且進而引發接觸這些活動及其作品的人，情感上的共鳴或省思，並提供與增強其知覺的感受性。

陳瓊花，藝術概論，1995

音樂的藝術歷程



電腦音樂在創作與呈現方面之特點

- 擴充調性
 - 1.微分音樂
 - 2.較少調感如噪音
- 精準地執行創作者所賦予之任務
- 機器不受人類演奏上的限制
 - 節奏與速度從人類限制中解放
 - 建構一種只存在於機械產物下的音樂
- 創作者完全地控制音樂各個層面
 - 從開始至作品完成，甚至到展演均不需假借第三人之手
- 可獲得立即回饋並及時修改及發展樂思

*曾毓忠, 音樂科技與科技音樂

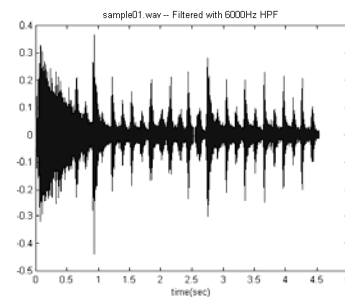
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- 結語

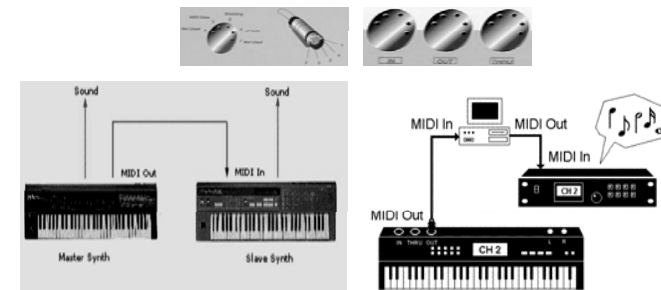
音樂呈現媒體

- 波形
 - 空氣
 - 唱片, 錄音帶
 - CD, MP3
- 符號
 - 樂譜
 - MIDI

伍佰-一生最愛的人 (0:10) 



Musical Instrument Digital Interface (MIDI)

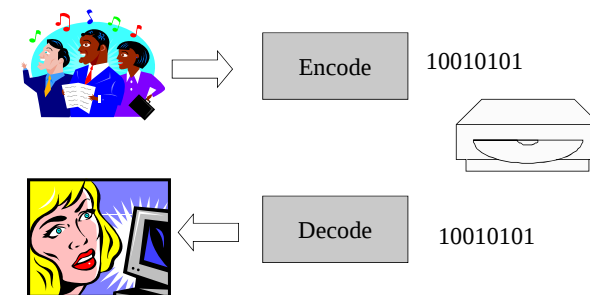


*曾毓忠, 音樂科技與科技音樂

MIDI 檔案

000000	4D 58 68 84 00 00 00 06	00 01 00 11 00 F0	MThd.....
000010	00 00 00 19 00 FF	59 02 FF 00 00 FF 58 04	Y...X
000020	04 02 18 08 00 FF 51 03	0A 2C 2A 00 FF 2F 00	Q.,**./.
000030	00 00 14 21 00	C0 00 00 B0 07 7F 00 80	A..O..P.
000040	00 00 AD 00 FF 05 02 A7	41 00 90 4F 7F 81 70 80	O*.....* * *
000050	4F 2A 00 FF 05 02 AA BA	00 90 * * *	

數位音樂

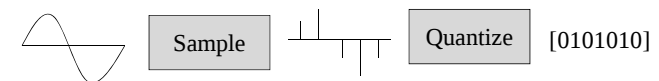


MP3 範例

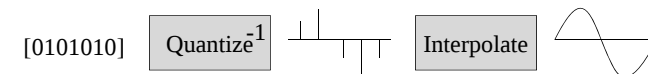
- castnets, 1.11MB  (0:07)
- castnets128, 104KB  (0:07)
- castnets96, 78.1KB  (0:07)
- castnets48, 39.2KB  (0:07)
- ftb_samp, 4.30MB  (0:26)
- ftb_samp128, 399KB  (0:26)

搏碼調變(PCM)技術

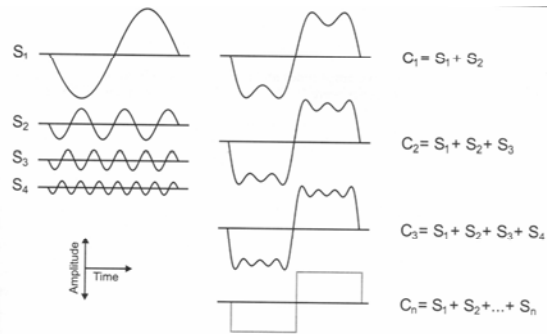
• PCM Encoder



• PCM Decoder

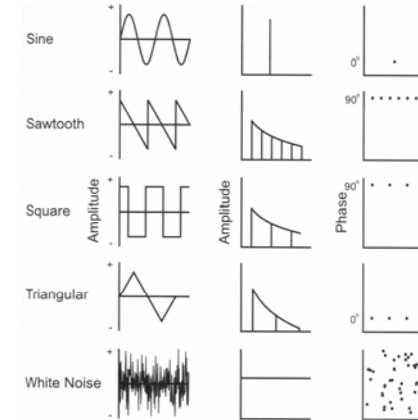


Fourier 定理



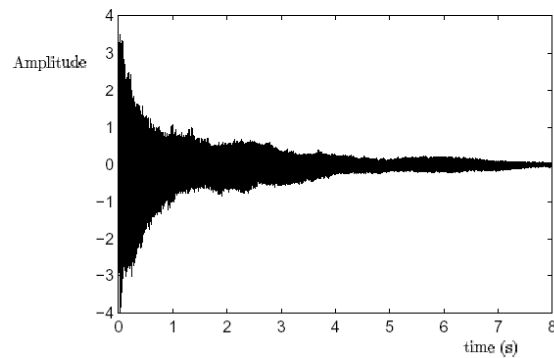
C. E. Speaks, Introduction to Sound, 3rd ed., Singular Publication Group, 1999.

頻譜(Spectrum)



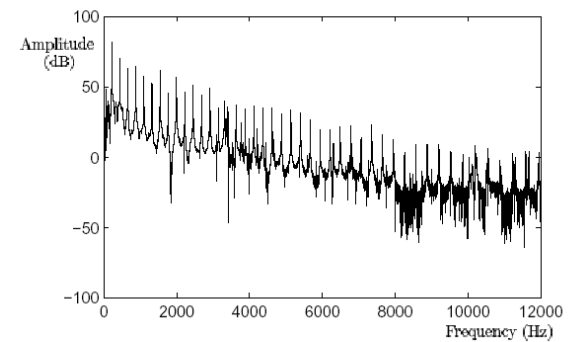
C. E. Speaks, Introduction to Sound, 3rd ed., Singular Publication Group, 1999.

Grand Piano Note C2



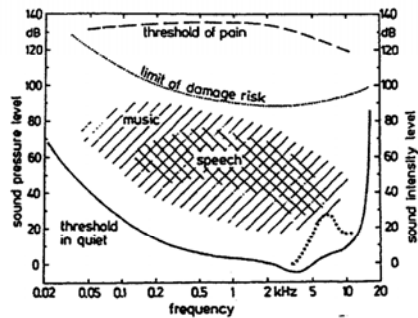
J. Bensa, Analysis and Synthesis of Piano Sounds using Physical and Signal Models, PhD thesis, Université de la Méditerranée, Marseille, France, 2003

Spectrum of Grand Piano Note A3



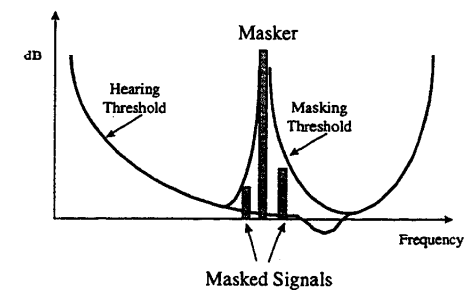
J. Bensa, Analysis and Synthesis of Piano Sounds using Physical and Signal Models, PhD thesis, Université de la Méditerranée, Marseille, France, 2003

聽覺區域



*M. Bosi and R. E. Goldberg, Introduction to Digital Audio Coding and Standards, Kluwer Academic Publishers, 2003.

頻域遮蔽效應

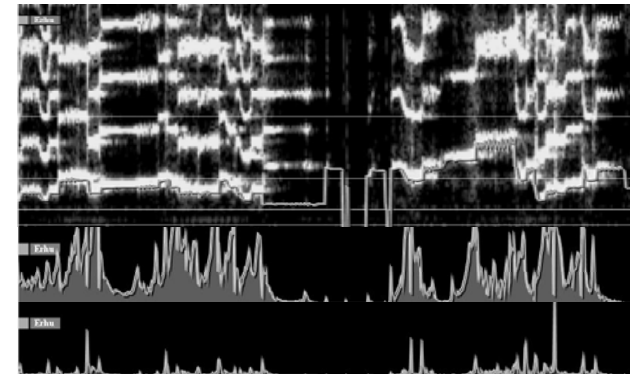


*M. Bosi and R. E. Goldberg, Introduction to Digital Audio Coding and Standards, Kluwer Academic Publishers, 2003.

聲音合成

- 頻譜合成
- FM
- 波形表
- Physical Model

二胡音樂(二泉映月)之頻譜合成



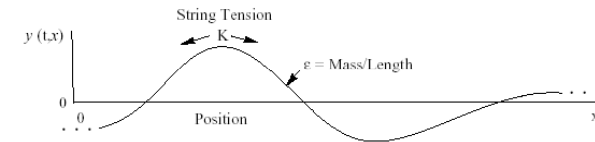
二胡原音 (0:23) 二胡合成 (0:23) 小號合成 (0:23)

*蘇文鈺, 蕭義崧

Physical Modeling Synthesis

- Synthesize sound of a musical instrument through computation based on its sound-generation model
- The artificial instrument can have the same parameters as the real instrument
- Expressivity of control is unlimited

Ideal Vibrating String



$$Ky'' = \varepsilon \ddot{y}$$

$K \triangleq$ string tension

$y \triangleq y(t, x)$

$\varepsilon \triangleq$ linear mass density

$\dot{y} \triangleq \frac{\partial}{\partial t} y(t, x)$

$y' \triangleq$ string displacement

$y' \triangleq \frac{\partial}{\partial x} y(t, x)$

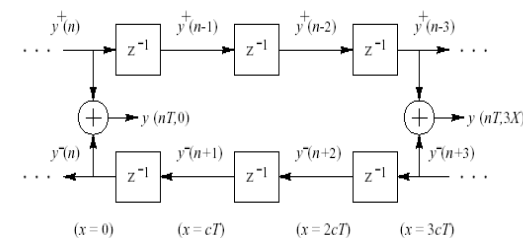
Piano Physics at Purdue (PPP) * Giordano



(0:28)

<http://www.physics.purdue.edu/piano/>

Digital Waveguide Techniques

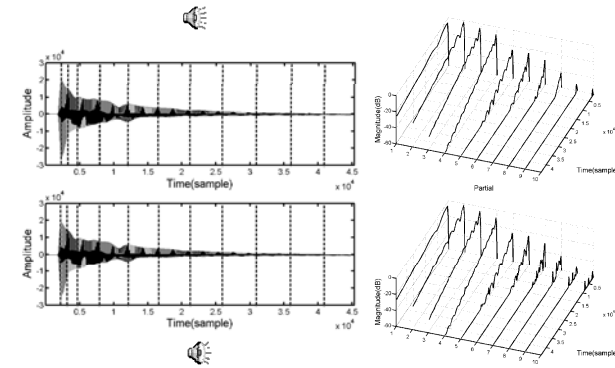


*J. O. Smith

Digital Waveguide Synthesis

- Slide Flute (CCRMA)  (0:21)
*J. O. Smith
- Harpsichord (CCRMA)  (0:13)
*J. O. Smith
- Marimba (CCRMA)  (0:19)
*J. O. Smith
- Titanic (NTU)  (1:07)
*連育廣

古琴聲的合成



*蘇文鈺, 梁勝富, 林進燈

電子樂器Theremin



(0:44)

<http://video.google.com/videoplay?docid=4959544989168783908&q=theremin>

電子樂器Theremin



Hypercello/Yo-Yo Ma



<http://brainop.media.mit.edu/Archive/Hyperinstruments/hypercello.html>

Chris Chafe, CCRMA



<http://www-ccrma.stanford.edu/~cc/sc2000.jpg>

Sensor Chair



<http://brainop.media.mit.edu/Archive/Hyperinstruments/chair.html>

數位喇叭



<http://www.digitaltrumpet.com.au/>

*S. Marshall and J. Morrison

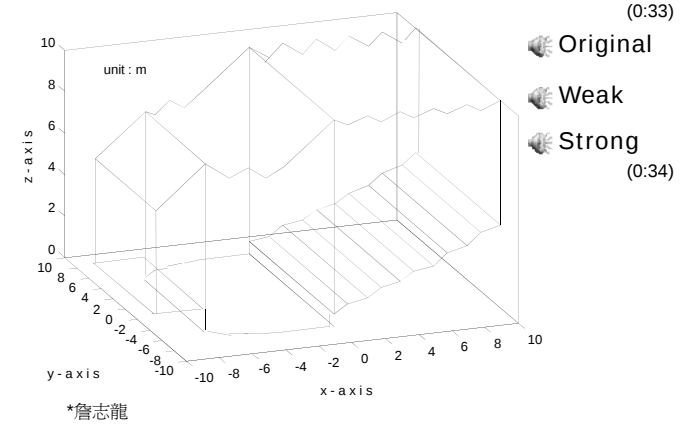
虛擬鋼琴



(0:48)

*蔡函辰

虛擬音樂廳

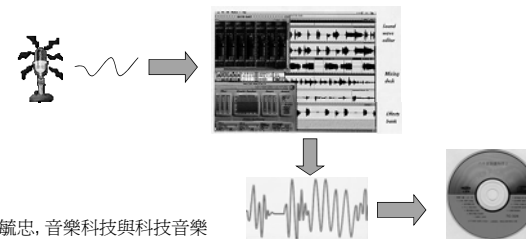


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電腦音樂創作過程

- 聲音素材選取
- 聲音素材編輯、組織、排序、混音
- 記譜、儲存、展演



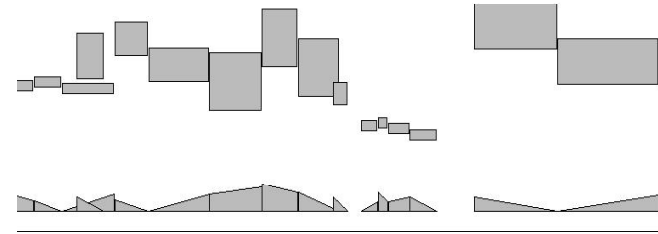
*曾毓忠, 音樂科技與科技音樂

趙菁文教授作品選段

- 天倪：古箏、小提琴、大提琴與電子預置音樂 (2006)
 - 古箏原音 (0:12)
 - granular synthesis 後的聲音 (0:21)
 - 成品選段 (0:59)
- 純化：打擊樂與預置電子音樂 (0:42)

電腦音樂記譜

Stockhausen: Elektronische STUDIE II (1954)



*曾毓忠, 音樂科技與科技音樂

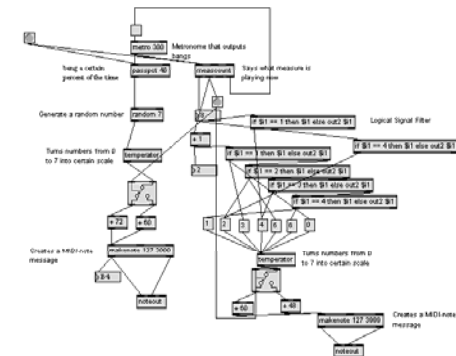
Tod Machover's Hyperscore

The Hogwarts Express
Kyuanghwa Song New York, USA (1:15)



http://www.hyperscore.com/featured_songs.html

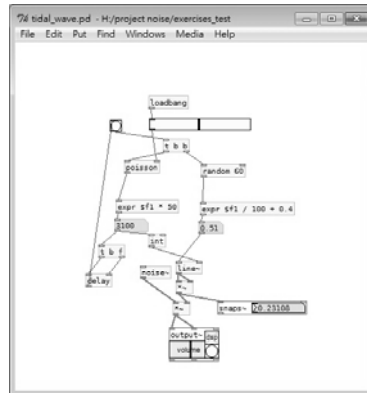
準則音樂 (Algorithmic Music)



(0:46)

*亞聖 · Harmonization (use MAX/MSP)

環境聲音轉換



*陳韋安, (Pure Data), 2010

電腦音樂展演



Stockhausen 展演他的電子音樂作品

*曾毓忠, 音樂科技與科技音樂

現場樂器或人聲加錄音

- 曾毓忠：斷簡殘編(2004) 為鋼琴與錄音帶(CD) 

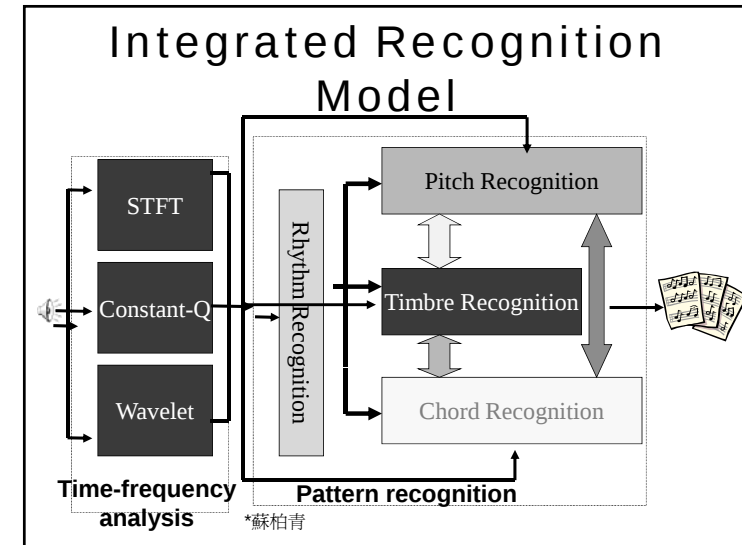
David Cope's Classical Music Composed by Computer

- Invention No. 2 (After Bach)  (1:28)
- Mozart, Opera Act 2, Scene 8  (1:19)
(After Mozart)
- Printemps (After Stravinsky)  (4:11)

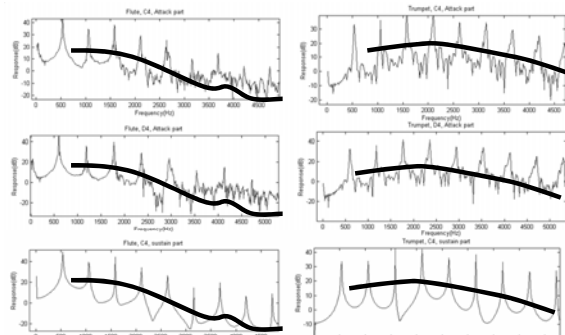
*Published by Centaur Records, 1997

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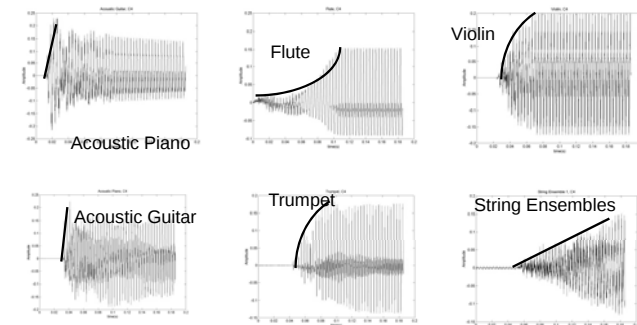


Spectral Shapes of Flutes and Trumpets



*蘇柏青

Slope of the Attack



*蘇柏青

Results of Timbre Recognition Unit in Monophonic Environments

	AP	AG	VI	TR	FL	SE	Recognition Rate
AP	16	2	0	0	0	0	88.89%
AG	6	10	0	0	0	2	55.56%
VI	0	0	13	0	0	5	72.22%
TR	0	0	0	15	2	1	83.33%
FL	0	0	0	2	16	0	88.89%
SE	0	0	1	0	0	17	94.44%

*蘇柏青

Total Recognition rate = 80.56%

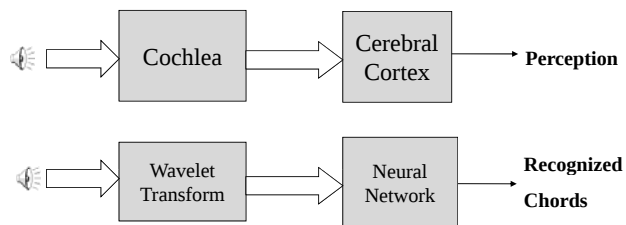
Results of Timbre Recognition Unit in Polyphonic Environments

	AP	AG	VI	TR	FL	SE	Recognition Rate
AP	10	7	0	0	0	1	55.56%
AG	7	6	1	1	1	2	33.33%
VI	0	2	8	2	1	5	44.44%
TR	2	2	0	11	2	1	61.11%
FL	1	0	2	2	10	3	55.56%
SE	2	2	5	1	0	8	44.44%

*蘇柏青

Total Recognition rate = 49.07%

Models of Chord Classification



*蘇柏青

Results of Chord Recognition Unit

	Number of the tested measures	Number of Correctly recognized measures	Recognition Rate
4 th movement of Beethoven's 5 th symphony	8	8	100.00%
Close to me (piano melody)	8	8	100.00%
Friends -by Emil Chou (popular song)	32	30	93.75%

*蘇柏青

Transcription Example

♩ = 108 ♩ = 108

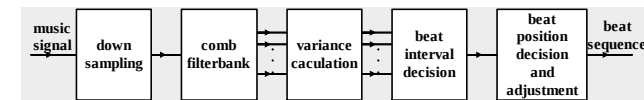
G D C Cm 3 fr. G D C Cm 3 fr.

Original Transcription Result

*蘇柏青

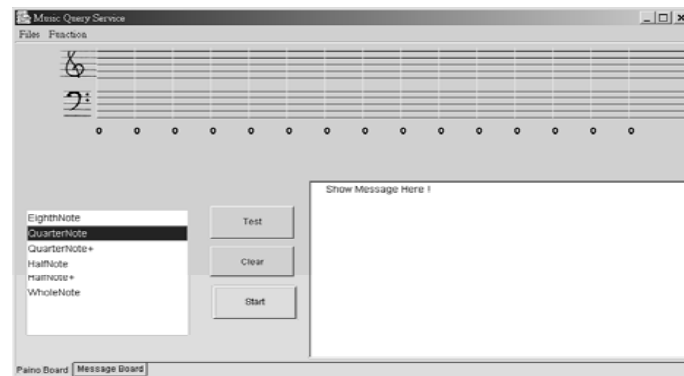
Beat Tracking System

- Off-line method  (0:12)  (0:12)
- Input signal sampling rate : 8 kHz  (0:33)
- Platform : MATLAB



*虞敬業

音樂搜尋系統



*黃耀樟

超級點歌王



*張智星

<http://www.supermbox.com.tw/>

自動伴奏



<http://www.cs.cmu.edu/~music/accomp/index.html>
*R. Dannenberg

聲樂自動伴奏系統示範

- <http://www.cs.cmu.edu/~music/video/CANGIO.MOV>
(1:09) *R. Dannenberg

Piano Tutor

- <http://www.cs.cmu.edu/~music/video/pianotutor.mov>
(4:11) *R. Dannenberg

Score Follower



<http://www.keeping-score.org/sites/default/files/swf/beethoven/beethoven-full>

Program MARSYAS



http://opihi.cs.uvic.ca/marsyas/index.php?page_id=0
*G. Tzanetakis

Classification Evaluation – 10 genres

Manual (52 subjects)
Perrot & Gjerdingen, M.Cognition 99

Automatic (different collection)
Tzanetakis & Cook, TSAP 10(5) 2002

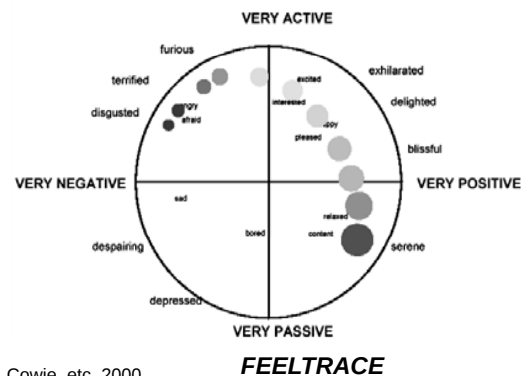
0.25 seconds 40%
3 seconds 70%

Gaussian Mixture Model (GMM)
10-fold cross-validation 61% (70%)



*G. Tzanetakis

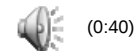
情緒辨識實驗



*R. Cowie, etc. 2000.

情緒表達顯著片段(SSEE)範例

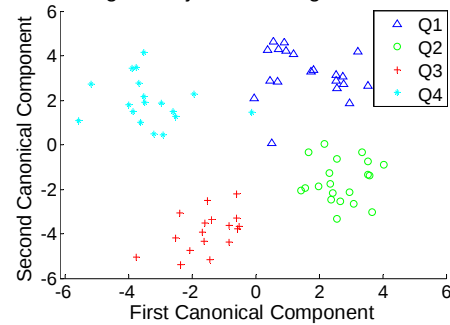
- “Hungarian Rhapsodies No 12 in F minor” (10:30) by Franz Liszt
(匈牙利狂想曲：李斯特)



(0:40)

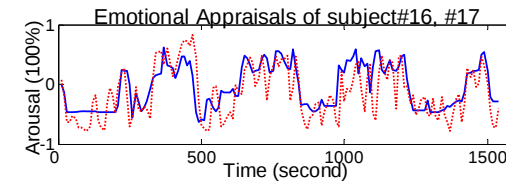
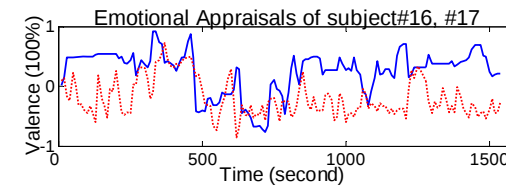
情緒辨識系統

Clustering of subject#16 using 55 Features



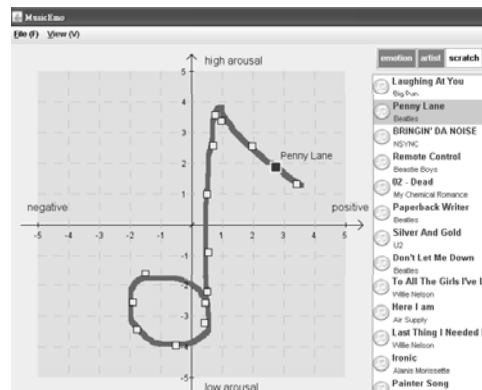
*吳天麟

尋找知音



*吳天麟

Mr. Emo



Y. -H. Yang, Y. -C. Lin, H. -T. Cheng, H. Chen, ACM'08, 2008

ISMIR



MIREX



Tasks in MIREX 2010 (1/2)

- Audio Test/Train
- Audio Cover Song Identification
- Audio Tag Classification
- Audio Music Similarity and Retrieval
- Symbolic Music Similarity and Retrieval
- Audio Onset detection
- Audio Key detection

Tasks in MIREX 2010 (2/2)

- Real-time Audio to Score Alignment (a.k.a Score Following)
- Query by Singing/Humming
- Audio Melody Extraction
- Multiple Fundamental Frequency Estimation & Tracking
- Audio Chord Estimation
- Query by Tapping
- Audio Beat Tracking
- Audio Structural Segmentation

Partial Performance Results in MIREX 2010

Submission Code	Summary Accuracy	Accuracy Per Testing Fold		
		0	1	2
WLJW1	0.5383	0.590	0.500	0.525
WLJW2	0.6417	0.735	0.595	0.595
BMPE2	0.5467	0.585	0.505	0.550
BRPC1	0.5867	0.645	0.575	0.540
BRPC2	0.5900	0.695	0.550	0.525
CH1	0.6300	0.705	0.615	0.570
CH2	0.6300	0.725	0.605	0.560
CH3	0.6350	0.710	0.640	0.555
CH4	0.6267	0.710	0.615	0.555

J. C. Wang, H. Y. Lo, S. K. Jeng, H. M. Wang, "MIREX 2010: Audio classification using semantic transformation and classifier ensemble," submissopn for MIREX2010

The 45 Selected Tags

metal	instrumental	horns	piano	guitar
ambient	saxophone	house	loud	bass
fast	keyboard	electronic	noise	british
solo	electronica	beat	80s	dance
jazz	drum machine	strings	pop	r&b
female	rock	voice	rap	male
slow	vocal	quiet	techno	drum
funk	acoustic	distortion	organ	soft
country	hip hop	synth	trumpet	punk

J. C. Wang, H. Y. Lo, S. K. Jeng, H. M. Wang, "MIREX 2010: Audio classification using semantic transformation and classifier ensemble," submission for MIREX2010

Music Features Used

Types	Feature Description	Dim
dynamics	rms	1
	centroid: mean	1
spectral	spread: standard deviation	1
	skewness	1
	kurtosis	1
	entropy	1
	flatness	1
	rolloff at 85%	1
	rolloff at 95%	1
	brightness: high frequency energy	1
	roughness: sensory dissonance	1
	irregularity: the degree of variation of the successive peaks	1
timbre	zero crossing rate	1
	spectral flux	1
	MFCC	13
	delta MFCC	13
	delta-delta MFCC	13
tonal	key clarity	1
	key mode possibility	1
	HCCDF	1
	chroma peak	1
	chroma centroid	1
	chroma	12

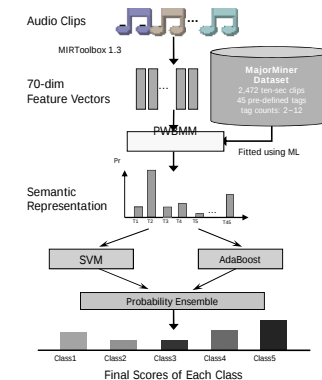
J. C. Wang, H. Y. Lo, S. K. Jeng, H. M. Wang, "MIREX 2010: Audio classification using semantic transformation and classifier ensemble," submission for MIREX2010

Music Mood Category

Class	Mood Components
1	passionate, rousing, confident, boisterous, rowdy
2	rollicking, cheerful, fun, sweet, amiable/good natured
3	literate, poignant, wistful, bittersweet, autumnal, brooding
4	humorous, silly, campy, quirky, whimsical, witty, wry
5	aggressive, fiery, tense/anxious, intense, volatile, visceral

J. C. Wang, H. Y. Lo, S. K. Jeng, H. M. Wang, "MIREX 2010: Audio classification using semantic transformation and classifier ensemble," submission for MIREX2010

System Flow Chart



J. C. Wang, H. Y. Lo, S. K. Jeng, H. M. Wang, "MIREX 2010: Audio classification using semantic transformation and classifier ensemble," submission for MIREX2010

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- 電腦與互動藝術
- 結語

歐洲MEGA計畫

- MEGA
 - Multisensory Expressive Gesture Application
- 2000-2003, 義大利University of Genova教授**Antonio Camurri**主導
- 利用多感測器環境進行非語言情緒表現的分析與互動
- 著重音樂表演與肢體動作
- <http://www.megaproject.org/>

多媒體互動音樂會



<http://www.megaproject.org/>

Disappearing Dancers



<http://www.megaproject.org/>

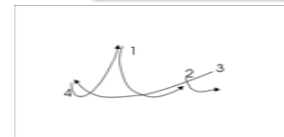
本土互動作品舉例

- 張耘之：大地之舞，WOCMAT2006
 - 以西非舞蹈為概念的演出，西非節奏樂器 Djembe 為輔，舞蹈者為聲響的觸發者，在線性的肢體移動當中，經過程式的 Transform，被轉換為數位的訊號，再以此訊號進行聲響或音符的對映(mapping)，將audio signal播放出來，由於舞蹈與 Djembe 必須同時存在，所以將造成鼓聲與電子擬聲在節奏內同時出現的狀態，若以西非傳統的節奏規則進行電子擬聲的行為規範，則將成為Poly-Rhythm的視覺與聲音的演出。

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*李務熙

指揮家程式



<http://www.ee.ntu.edu.tw/~b87020/Conductor.htm>

*李務熙

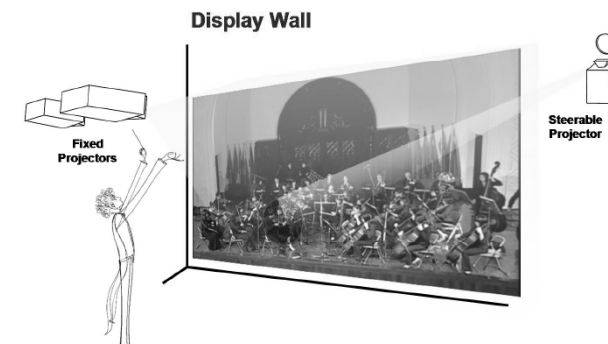
指揮家程式示範影片



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*李務熙

Virtual Conduction System

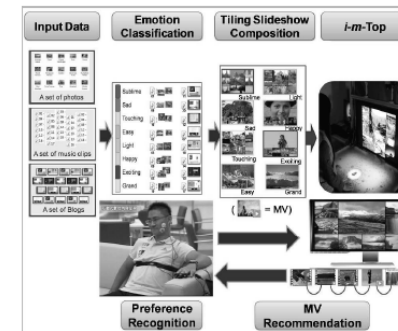


W. T. Peng., etc., "Virtual Conduction System with Multi-Resolution Wall Display,"
2007 IEEE International Conference on Multimedia and Expo., July 2007.

Saxphon Accompaniment System

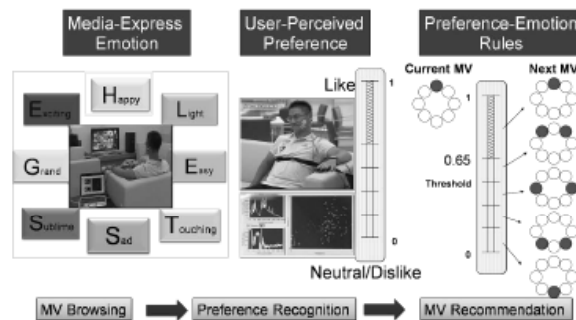


Interactive Content Presentation



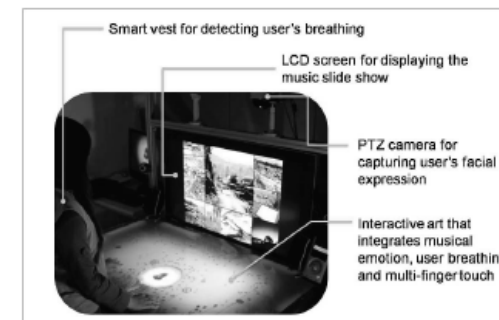
T. L. Wu, etc., "Interactive content presentation based on expressed emotion and physiological feedback," MM '08, Vancouver, Canada, 2008

Interactive Content Presentation



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結語

- 科技：正德、利用、厚生
- 音樂：人生潤滑劑
- 電腦應用到音樂的創作、呈現、聆聽等各個層面，影響深遠廣泛
- 電腦音樂結合科技、藝術、心理、生理等領域，密切與人類生活相關
- Have fun!

**THANK
YOU**